AFIT/GEE/CEV/92S-8

# RISK REDUCTION AS A CRITERION FOR MEASURING PROGRESS OF THE INSTALLATION RESTORATION PROGRAM

THESIS

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# RISK REDUCTION AS A CRITERION FOR MEASURING PROGRESS OF THE INSTALLATION RESTORATION PROGRAM

THESIS

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## Abstract

To properly manage the Installation Restoration Program (IRP) in the future, the Air Force (AF) needs a method to assess progress based on improvements in environmental conditions. An integral part of evaluating progress toward protecting human health and the environment is the assessment of risk reduction as a result of cleanup actions.

The AF currently uses the Defense Priority Model (DPM) to assist in setting priorities for funding remedial actions at IRP sites. The DPM provides a numerical score for IRP sites representing the relative potential risk based on the environmental conditions at a site before remedial actions are taken. This study investigates using the DPM to provide an indicator of progress based on improvements in environmental conditions at IRP sites.

Rescoring the DPM to represent site conditions after remedial actions shows a reduction in relative risk as contaminant levels and transport potential are changed. A multi-criteria decision modeling techniques was used to combine the relative risk data with other administrative measures of progress currently used by the AF. The results provide a method to rank the accomplishments at IRP sites.

RISK REDUCTION AS A CRITERION FOR MEASURING PROGRESS OF THE INSTALLATION RESTORATION PROGRAM

## I. Introduction

### General Issue

The Air Force (AF) has spent 1.7 billion dollars over the last eight years to address the problems of sites contaminated with hazardous substances An additional seven billion dollars will be required fc remedial efforts at thousands of sites over the next decade (20). To justify and properly manage resources in the future the AF needs a method to assess progress based on improvements in environmental conditions at contaminated sites.

The AF currently uses administrative milestones, such as number of sites closed, to measure progress toward cleaning up contaminated sites. These milestones do not accurately reflect what has been accomplished to improve the environmental condition at contaminated sites (3:144). Don R. Clay, the Environmental Protection Agency's (EPA) top official responsible for the national "Superfund" cleanup program, states:

> Attention has been focused on the number of sites deleted from the National Priorities List (NPL) as the only measure of Superfund accomplishment. Evaluating Superfund's success by tallying site deletions is not only disappointing, it is inherently misleading.Success for Superfund is more appropriately measured in terms

> of the successive, interim actions taken to control the worst problems at the worst sites. (3:144)

An integral part of evaluating progress toward protecting human health and the environment is the assessment of risk reduction (6:1333). Without assessing risk reduction associated with remedial actions there is no basis for measuring improvements in environment conditions (7:1535).

Installation Restoration Program (IRP). The AF established the Installation Restoration Program (IRP) to address the problems of sites contaminated by hazardous waste. The AF is required to comply with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and the Superfund Amendments and Reauthorization Act of 1986 (SARA). These laws are popularly known as the Superfund Program. Section 211 of SARA, known as the Defense Environmental Restoration Program (DERP), specifically states the role of Department of Defense (DOD) facilities in complying with CERCLA/SARA. The AF IRP is a subcomponent of DERP. The objectives of the IRP are consistent with the DERP as stated in SARA Section 211 (5:59,60):

> The identification, investigation, research and development, and cleanup of hazardous substances, pollutants, and contaminants. (24:1670)

The Defense Environmental Restoration Account (DERA) was established to support the DERP and its subcomponents, such as the Air Force IRP. DERA funds are appropriated

annually and are centrally managed by the Office of the Deputy Assistant Secretary of Defense (Environment) (OSD(E)). CERCLA/SARA requires an annual report to Congress on the expenditure of DERA funds and the progress of the DERP.

The only measures of progress used thus far in the IRP have been based on administrative or legal milestones. There is currently no method for evaluating improvement of environmental conditions as a result of remedial actions at IRP sites. To justify and manage the resources for the IRP, the AF needs a method to assess progress based on tangible environmental improvements. Because of the high level of interest and oversight, it is important for the AF to show progress toward restoring the environment and eliminating the threat posed by the worst sites.

## Research Problem

In order to develop a method to assess progress based on improvements in environmental conditions at contaminated sites two research problems will be addressed. First, a method to quantify risk reduction at IRP sites needs to be developed. Second, a method for combining risk reduction data with other factors (such as administrative milestones) to measure progress needs to be developed.

## Research Objectives

The purpose of this study is to develop a method to use risk reduction as a criterion to assess progress for the

IRP. This study investigates the application of current risk assessment techniques to quantify reduction in environmental risk at IRP sites resulting from remedial actions. Once reduction in risk can be quantified, a method will be developed to consider risk reduction along with other factors to provide a more meaningful measure of progress for the IRP.

## Definition of Progress

For this research, progress is defined as the measurement of accomplishment toward improving environmental conditions resulting from actions taken as part of the IRP. Measurements of progress are needed to compare the relative accomplishments of one project or program to another. This allows the popular use of a scorecard to compare the accomplishments made by various organizations within the AF. Measurements of progress are applicable for a site by site comparisons or by base, MAJCOM, or service agency.

## Application and Limitation

This research addresses the measurement of progress from the point when decisions are made for remedial actions (or site closures) at IRP sites. The intent of the research is to develop a method to compare the accomplishments of actions taken at IRP sites. Extensive remedial actions necessary at the worst sites will be compared to lesser actions taken to close sites where little or no environmental threat exists.

Existing methods for measuring risk and multi-criteria evaluation of alternatives will be used to demonstrate how they can be used to assess progress. It is not the focus of this research to evaluate or validate the methods used to assess risk at IRP sites. Also, it is not the intent of this research to determine that a particular method for multi-criteria evaluation of alternatives is more suitable than others. A wide variety of methods to measure risk and evaluate alternatives may be applicable for the methods developed in this study to measure progress.

# II. Literature Review

"The lack of assessment of risk reduction is a major weakness in the present decision making process [for the Superfund Program]" (6:1333). The objective of this research is twofold: develop a method to assess reduction in risk at IRP sites and to rank or prioritize sites based on progress. First, a method to evaluate reduction in risk needs to be developed. The following provides a brief discussion of how risk is measured and several methods used to evaluate environmental risk at hazardous waste disposal sites.

The second objective is to use risk reduction data along with other factors, such as administrative milestones, to assess the accomplishments of the IRP. Various multi-criteria evaluation techniques have been used in many applications to rank alternatives, where each of the alternatives have many factors to consider. These techniques can be used for ranking the accomplishments of IRP actions based on several factors that indicate progress. This chapter provides a discussion of the literature reviewed on multi-criteria evaluation methods and various Multi-Criteria Decision Models (MCDM) that are available.

## Measures of Risk

Risk assessment provides the scientific basis necessary for making environmental management decisions (17:192).

Risk assessment is broadly defined by Cohrssen and Covello as "the technical assessment of the nature of risk" (4:1). There are a variety of purposes, applications, and methods for assessing the risks to human health and the environment associated with IRP sites. The various applications include both qualitative and quantitative methods to describe risk (19:18). There are two types of quantitative measures of risk commonly used in the IRP and Superfund, they are quantitative risk assessments (for assessing excess risk) and relative risk models (16).

Quantitative Risk Assessment. Quantitative risk assessments are used to estimate the excess risk or adverse impacts of contaminants to exposed populations and the environment (19:18). Risk assessments involve four steps: hazard identification, dose-response assessment, exposure assessment, and risk characterization. The results of risk assessments are expressed in terms of excess risk or the probability and severity of an adverse response to an exposure to a contaminant (16).

There are defined EPA guidelines for assessing excess risk. However, at each site, typically a wide variety of inferences can be made from the data available and the EPA guidelines. The methods currently used for quantitative risk assessment have been highly controversial within the field of environmental management. Quantitative risk assessments require condensing highly uncertain, frequently conflicting, and often ambiguous data. The results are

inferred from data extrapolated well beyond what can actually be measured to assign a value that represents the excess risk to a certain population (17:191). The controversial nature of the science of risk assessment as well as local regulatory, political, and social influences has make it difficult to use a consistent method for quantitative risk assessment. No standard method has evolved for assessing the excess risk posed by environmental hazards.

Relative Risk Assessment. The CERCLA/SARA legislation required EPA to develop a system to assess the relative degree of risk to human health and the environment at potentially contaminated sites. The EPA developed the Hazard Ranking System (HRS) to provide a quantitative assessment of the relative threat posed at potential Superfund sites (27:1).

> The HRS is used as a screening tool to identify those sites that represent the highest priority for further investigation and possible cleanup under CERCLA. Its purpose is not to fully characterize the source and extent of the contamination. Rather, its purpose is to evaluate the potential of uncontrolled hazardous substances to cause damage to human health or to the environment. Uniform application of the HRS nationwide enables EPA to evaluate sites relative to each other with respect to actual or potential hazards. (27:2-3)

The HRS uses data generated during the Preliminary Assessment (PA) and Site Inspection (SI) phases of the CERCLA remedial action process. The HRS score is used to determine if a site is placed on the NPL for further investigation and cleanup in the Superfund program (27:1).

The HRS is designed to be a simple numerical model that assigns a score from 1 to 100 based on:

1. The likelihood that a site has released or has the potential to release contaminants to the environment.

2. The characteristics of the waste (toxicity and waste quantity).

3. The people or sensitive environments affected by the release. (27:1)

Other federal agencies developed relative risk scoring systems similar to the HRS to determine which sites on their facilities warranted extensive investigation. The Department Of Energy (DOE) developed the Multimedia Environmental Pollutant Assessment System (MEPAS). "MEPAS is used to prioritize hazardous, radioactive, and mixed-waste sites, based on their potential hazard to public health (25:iii)."

The AF developed the Hazard Assessment Risk Model (HARM) in the early 1980s to identify IRP sites based on the initial, limited investigations conducted at potential sites. The Defense Priority Model (DPM) evolved from the AF HARM with extensive revisions and peer reviews by numerous experts in the field of risk assessment. The DPM was developed to assist AF and DOD managers in setting priorities for funding remedial actions at IRP sites (12:1-3).

The DPM is used after extensive Remedial Investigations (RI) have been completed to provide a numerical score representing the relative risk to human health and the

environment. The DPM calculates relative risk by considering the type and amount of contaminant(s) along with potential transport pathways and potential receptors (12:1-3).

## Multi-Criteria Evaluation

If there were only one criterion or factor to consider when evaluating alternatives (progress at IRP sites) ranking the alternatives would be simple (14:165). However, as in the case of this research, there is often more than one factor to consider when evaluating various alternatives such as risk reduction and site closure status. Each factor can affect the evaluation of alternatives individually and may be difficult for the decision maker to compare with the other factors (29:139). Multi-Criteria Decision Models (MCDM) are used to evaluate each of the alternatives with respect to the others using a pre-specified decision rule or set of rules (2:8).

Several MCDM techniques have been developed over the last fifteen years for a wide range of applications. There are three major types of MCDM techniques: outranking, utility based, and distance based models (9:132). The various MCDMs differ in how the criteria are weighted to represent their relative importance with respect to other criteria (29:184).

No one type or technique of MCDM is necessarily the best for a given application or decision maker (9:134). The

validity of an MCDM should be judged by how it measures a decision maker's preferences with sufficient accuracy and consistency (9:134). The following provides a brief discussion and examples of the three types of MCDMs.

Outranking Models. The outranking method measures the level of content or discontent for each alternative by a pairwise comparison of the alternatives for each criterion. An advantage of this method is "its ability to incorporate qualitative data into the analysis without explicit quantification of criteria ratings" (8:16). For example, it could be stated that cleaning up a heavily contaminated site is better than closing a site with little or no contamination or threat to the environment.

The level of content for an alternative is a weighted measure of the number of criteria in which the alternative is preferred to another alternative. The level of discontent is measured by developing a scale to compare each criterion between the "best" and the "worst" for that criterion. The level of content and discontent are expressed as a percentage (8:17). The ELECTRE MCDM is a widely used example of an outranking model with various case studies discussed in the literature (9:139). "The idea in ELECTRE is to choose those systems that are preferred for most of the criteria and do not cause an unacceptable level of discontent for any one criterion" (8:16).

Utility Based Models. Utility or value based techniques are used to model the decision maker's preference

for considering the various factors (or attributes) when evaluating alternatives (9:136).

> Utility is defined as the subjective benefits derived by the decision-maker from the achievement of the stated goals or objectives. The motivating factor of multiattribute utility theory is that decision maker's utility function can be specified numerically. (8:19)

The weight for each factor is assigned to represent the user's value or utility of the information provided by the factor. Mathematical restrictions require that the factors considered and the utility or value assigned to the factors must be mutually independent of each other (8:19). For example, a decision maker's utility for closing out a site may be twice as important as whether any threat to the environment has been eliminated. Therefore, the attribute representing environmental risk would be given a weight one half times the weight of the attribute for closing a site.

Distance Based Models. The concept of distance based techniques is to find the most satisfying alternative. The alternative selected minimizes the distance between the alternative and a reference set of criteria values (9:135).

> "Distances are used as a proxy measure for human preference. Distances show the degree of resemblance, similarity, or proximity of alternatives with respect to individual criteria." (9:135-136)

There are several types of distance based models, they differ in the way a reference point is selected and how they relate to the reference point. In most cases the reference point represents an infeasible or idea alternative in which the alternatives are related (9:136). An example of this

technique is compromise programming and the displaced ideal model where the alternatives are ranked by their closeness to an ideal solution (2:321-325).

Another type of distance based technique is cooperative game theory where alternatives are compared to a minimum level reference point. The objective of cooperative game theory models are to rank alternatives based on the maximum distance from the reference point (8:19).

# III. Methodology

This study investigates use of risk reduction as a criterion to assess progress of the IRP. The first objective was to demonstrate a method to quantify risk reduction at IRP sites. Once the reduction in risk can be quantified, the second research objective was to combine risk data with other factors currently used to measure progress. A multi-criteria evaluation technique was used to rank the accomplishments of actions taken at IRP sites using risk data along with other factors.

The following provides a description of the methodology that was used to accomplish the research objectives. Figure 1 on page 15 shows a flow diagram of the steps that were followed to carry out the research objectives described below. The results of the research were presented to experts in the field to determine if the methods developed to assess progress provide a viable management tool. The methodology to analyze and evaluate the results of the research is also described in this chapter.

## Measure Reduction in Risk

Remedial actions at IRP sites typically involve reducing the volume of the contaminants and/or reducing the potential for the contaminants to be transported. As progress is made towards cleaning up a site, various factors used to measure risk change. A risk model that is currently

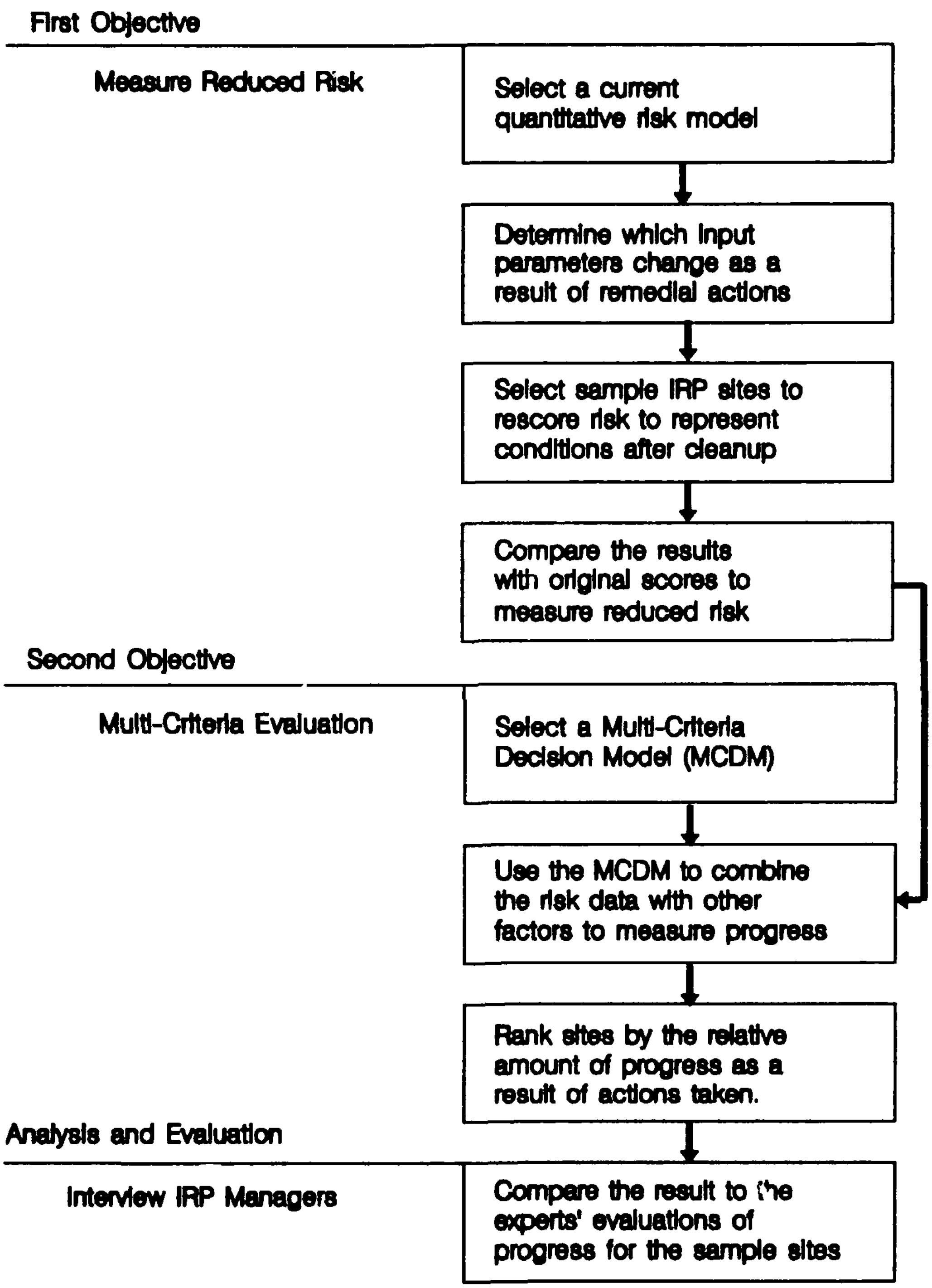



**Figure 1.** Flow Diagram of the Research Methodology

used to measure risk at IRP sites was selected to measure reduced risk as site conditions are improved. The model selected should reflect a change in environmental risk as inputs for contaminant levels and transport pathways are changed as result of remedial efforts.

To evaluate the model's application as a tool to assess reduced risks, the following investigative objectives were carried out:

1. Identify the input variables to the model that can be changed or affected by remedial actions.
2. Rescore sample sites by changing the variable input parameters to reflect environmental conditions after remedial actions are taken.

The purpose for rescoring the sites was to investigate the model's sensitivity to the input parameters that can be affected by remedial efforts. This effort was simply to determine if a change in environmental risk can be measured with the model. The original scores were compared to the rescore values to determine if the DPM can predictably show a reduction in risk. It was not the focus of this research to evaluate or validate the methods used by the model selected to calculate risk at contaminated sites.

Once a risk model was selected, sample IRP sites were selected to measure the potential risk reduction. The sample IRP sites were chosen from sites where the environmental risk has previously been assessed using the risk assessment model selected. Each site was rescored by

changing the variable input parameters to reflect environmental conditions after remedial actions have taken place. Each variable parameter will be changed to represent the best possible environmental condition achievable by remedial actions. Although the remedial actions actually chosen for IRP sites may not result in achieving the best possible scenario for every parameter, the DPM rescore represents the maximum amount of reduction in risk possible for a site.

Combine Risk Data with Other Factors

A multi-criteria evaluation method was selected to consider risk data along with other administrative factors currently used to measure progress. The MCDM selected was used to rank the accomplishments at the sample sites with the risk reduction data generated by rescoring the DPM. As discussed in the literature review, the various MCDMs differ in how the criteria are weighted to represent their relative importance with respect to other criteria (2:184). No one type or technique of MCDM is necessarily the best for a given application or decision maker (9:134). The validity of an MCDM selected was evaluated by how it emulates expert IRP managers' preferences for ranking the accomplishment of IRP actions.

The input of risk data to the MCDM consisted of three measures related to environmental risk. First, the original risk score or in other words the measure of risk that

represents the environmental conditions at the site prior to any remedial actions. Second, the measure of potential for risk reduction at a site. This was measured by taking the difference between the original score from the risk model selected and the rescore results from the first research objective. The third input related to risk was the amount of potential risk reduction achieved at a site. This allowed a comparison of sites where the most extensive remedial action for a site was not carried out or where a remedial action at a site may be only partially completed.

The risk data was combined with the administrative measure of progress currently used by the AF which is whether the site has been closed out (as defined by HQ USAF/CEV guidance). For the purpose of demonstrating the results to expert IRP managers, the data used in the MCDM for the site closure status and the third risk factor (potential risk reduction achieved) was made to represent realistic site scenarios. The data for these two factors had to be made up since the sample sites have not been cleaned up yet and the actual data was not available. The data was made up to allow the research to demonstrate and evaluate the methods developed over the full range of various IRP site status scenarios. Expert interviews used to analyze the results of this research were also used to ensure that the range of scenarios created with the data was reasonable and applicable.

## Analysis and Evaluation

To evaluate the results of the research personal interviews with experienced IRP managers were conducted. The interviews consisted of presenting the results of the research to experienced managers to determine if the methods developed provide a tool for managing the IRP. The experts' opinions concerning the application of the research to their management concerns were documented and reported as part of the analysis and evaluation in Chapter VI.

An unstructured interview was used to allow an open exchange of the experts' specific concerns related to measuring progress of the IRP. This interview method was selected to allow the researcher to explore the applications of the research for specific IRP management concerns (10:324). To evaluate the research the experts were asked if the methods developed provide a viable or more meaningful assessment of progress for managing the IRP.

A disadvantage of this method of interviewing is that the responses may have been biased by the researcher's interview techniques (10:328). This disadvantage will be minimized by allowing the experts to address their specific concerns related to measuring progress of the IRP. However, this research was based on the assumption that the lack of using risk reduction data as criteria for making decisions is a common concern among IRP managers. This assumption was supported by the interviews of IRP managers, review of

current periodical literature, and the researcher's experiences as an IRP manager.

The experts interviewed were selected to represent various levels of the AF environmental management organizational structure. Experts at HQ USAF/CEVR were selected to evaluate the research from the perspective of managing the AF-wide IRP. Experts from two MAJCOMs were selected to evaluate the application of the research for their specific management requirements. The experts from the MAJCOMs were chosen based on their expression of a need for a better or more meaningful method to assess progress and their willingness to participate.

Expert selection was also based on the following qualities:

1. Position as an IRP manager responsible for executing the program.
2. Experience and knowledge of the management issues related to the IRP.
3. Authority to represent their organization in the interview.

## IV. Quantification of Reduction in Risk

The DPM is used by the AF and DOD to determine the IRP sites that pose the greatest risk to human health and the environment. The application of the DPM to measure reduction in risk after remedial actions have been taken will be investigated. The DPM was selected for this research because the AF currently uses the model to assess the relative risk of all IRP sites where funding for remedial action has been requested. The senior managers of the AF IRP have accepted the DPM as an appropriate tool to measure relative risk at IRP sites (15). The following provides a detailed description of the DPM and describes how the model is used to measure reduction in risk at sample IRP sites.

### Defense Priority Model (DPM)

The DPM was developed to assist AF and DOD managers in setting priorities for funding remedial actions at IRP sites. The DPM provides a method to rank the potential threat to human health and the environment posed by individual sites. A score is calculated for each IRP site which represents the relative environmental risk at the site (21:1). The following is a brief discussion on the history of the development of the DPM and an explanation of the methodology used to calculate relative risk scores for IRP sites.

History. The basic philosophy and methodology used by the DPM was initially developed for the AF Hazard Assessment Risk Model (HARM) in 1984. The HARM was developed during the early stages of the IRP (site identification phase) to evaluate potential sites for further consideration in the cleanup program. An arbitrary HARM score was chosen to delineate which potential sites would be identified as IRP sites and move to the subsequent phases of the program. The original HARM was reviewed and tested extensively which led to significant modification and the development of HARM II (12:2).

HARM and HARM II were developed for the AF under an interagency agreement with DOE at the Oak Ridge National Laboratory (12:2). The algorithms and inputs for the model were adapted to computerized Artificial Intelligence (AI) application software packages (22:5).

In 1987, The Office of the OSD(E) proposed to use the method developed for the HARM II to establish a risk based priority ranking of all sites in DOD. HARM II was renamed the DPM and DOD continued the development of the model (12:4). DOD continued the development of the DPM under a contract with privately owned consulting firms (13).

DOD formally announced their intention on using the model to establish a risk based priority for allocating funds for remedial action and solicited comments on the HARM II methodology. Comments were received from the EPA, several states, and other interested parties. A formal

response was provided by DOD and the comments were incorporated into DPM. The first version (version 2.0) of the DPM was released for use by the DOD components in 1989. Version 3.0 and Version FY92 have subsequently been released to incorporate additional comments received from EPA and the states during their review of the earlier versions. The automation of the model has evolved to more powerful and sophisticated AI packages and C computer language (22:1-7).

To validate the DPM's methodology, the model was submitted to the National Academy of Sciences (NAS) for review and comment. An interim response from the NAS was published in June of 1992. The AF and DOD are currently developing a response to the criticisms and concerns expressed by the NAS in the interim report (13).

Methodology and Structure. The DPM provides a numerical score representative of relative risk. The relative risk score is a function of three factors: the contaminant(s) hazard, the transport pathways, and the potential receptors. The DPM is made up of three segments to address each of the factors above. First scores are generated within each segment. Subscores are then calculated for eight scenarios of transport pathways and potential receptors (21:1). The final score is calculated by weighing and combining the subscores using an exponential algorithm (22:2-9,2-10).

The methodologies for scoring of each of the segments of the DPM are briefly discussed below. The segments are

described in the order in which data is input into the model. First the pathway segment is scored. Second, contaminant hazard scores are calculated for each pathway. The potential receptor segment is scored last. The methodology used to combine the segments is discussed next. The final section provides a description of the algorithm used for the computation of the final score. The complete algorithm for calculating a DPM score is provided in Appendix A.

<u>Scoring Pathways</u>. The pathways segment of the DPM ranks the potential for contaminants to migrate from the disposal site. There are four contaminant transport pathways considered by the model. The pathways are "surface water via over land flow routes, the groundwater, or the air through volatilization or adhered to dust" (21:7). A separate score is calculated for each pathway (21:7).

To calculate each pathway score there are three components of information concerning the conditions at a site. The first type of information relates to the potential for contaminants to enter the pathway. There are various input parameters for each of the pathways that indicate the relative potential for the contaminant to enter the respective pathways (21:A-1). The second component is the "waste containment effectiveness factor" (21:A-1). This factor indicates the potential for contaminants to migrate once they are in the transport media. The third component

is the amount of contaminant(s) or the "waste quantity factor" (21:a-1) associated with the site (21:A-1 to A-4).

The DPM uses two different methodologies for scoring each pathway depending on whether a contaminant release has been observed (measured). If a contaminant release is observed in a transport medium the score for the potential for the contaminant(s) to enter the respective pathway is 100 (maximum normalized score). The input parameters to score the potential for the contaminant(s) to enter the pathway (the first component) are skipped. The scores for the second and third components are summed and normalized to provide the overall score for the pathway (21:A-1 to A-4).

If no release has been observed then the input parameters for the first component are used to score the potential for a contaminant to enter the pathway. The resulting score is normalized and the multiplied by the sum of the score for the second and third components. The new result is normalized to provide the overall score for the pathway (21:A-1 to A-4). A copy of the algorithm for scoring the pathways segment of the DPM by hand is located in Appendix A, pages 69 to 72.

Scoring Contaminant Hazard. The contaminant hazard scoring segment of the DPM ranks the human health hazards and ecological hazards of the contaminant(s) of concern at a site. The model calculates the eight following separate hazard/pathway scores (21:55):

1. human health hazards of surface water contaminants,
2. ecological hazards of surface water contaminants,
3. human health hazards of ground water contaminants,
4. ecological hazards of ground water contaminants,
5. human health hazards of air/soil volatile contaminants,
6. ecological hazards of air/soil volatile contaminants,
7. human health hazards of air/soil dust contaminants, and
8. ecological hazards of air/soil dust contaminants. (21:55)

The DPM uses various methodologies for calculating hazard/pathway scores depending on whether a contaminant has been observed (measured) for the respective pathway. If contamination has been detected the concept of Average Daily Intake (ADI) is used for scoring human health hazards. The highest observed concentration for each contaminant is used to calculate daily intake which is divided by the benchmark ADI for the contaminant. A quotient is calculated for each contaminant and summed to provide a score for the surface water and air/soil pathways. For the groundwater pathways the quotients are divided by a retardation factors calculated for the respective contaminants and then summed to provide the human heath hazard score (21:55).

The procedure for calculating ecological health hazards are the similar. The highest observed concentrations are divided by benchmark concentrations for ecological receptors for the respective pathway (21:55).

For calculating the total human health and ecological hazard scores for the groundwater and surface water pathways all contaminants known to be present at a site are considered. The DPM users manual list two conditions that defines contaminants that are known to be present:

1. it is a principle component of the materials that were placed or spilled on the site, or

2. it has been detected in a chemical analysis of site soils at a level that represents an increase above background. (21:61,68)

Human health hazard scores for contaminants where no detectable concentration levels are observed the calculations are based on the maximum ADI. For the ecological hazard scores the calculations are based on the benchmarks for toxicity for the appropriate ecological receptors (21:55). When no detectable concentration of contaminants can be observed for the air/soil volatile and the air/soil dust pathways the contaminant hazard scores are set to zero (21:75,78).

Scoring Receptors. The receptors scoring segment ranks the potential for humans and ecological resources to be exposed to contaminates that have migrated from a site. The model calculates scores for six types of receptors:

1. human health receptors of surface water contaminants,
2. ecological receptors of surface water contaminants,
3. human health receptors of ground water contaminants,
4. ecological receptors of ground water contaminants,
5. human health receptors of air/soil contaminants and,
6. ecological receptors of air/soil contaminants (21:79).

Receptors scores for the air/soil contaminants are scored once which includes both the air/soil dust and air/soil volatile pathways (21:79). Each of the receptors scores are calculated base on input parameters which provide information about the land uses, water resources, demographics, and sensitive environmental conditions around the site (21:A-9 to A-11).

Combining Segment Scores. The scores from the pathway, contaminant hazard, and receptor segments are multiplied to generate eight subscores. Each segment score is normalized and equally weighted (22:2-6). The subscores are calculated using the algorithm shown in Figure 2. The human health and ecological subscores for the air/soil dust and air/soil volatile are compared to select the most conservative scores for the air/soil pathway. The highest

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Surface Water Human Health Score** | = | **Surface Water Pathway Score** | x | **Surface Water Human Health Hazard Score** | x | **Surface Water Human Receptor Score** | **/10,000** |
| **Surface Water Ecological Score** | = | **Surface Water Pathway Score** | x | **Surface Water Ecological Hazard Score** | x | **Surface Water Ecological Receptor Score** | **/10,000** |
| **Ground Water Human Health Score** | = | **Ground Water Pathway Score** | x | **Ground Water Human Health Hazard Score** | x | **Ground Water Human Receptor Score** | **/10,000** |
| **Ground Water Ecological Score** | = | **Ground Water Pathway Score** | x | **Ground Water Ecological Hazard Score** | x | **Ground Water Ecological Receptor Score** | **/10,000** |
| **Air/Soil Volatiles[1] Human Health Score** | = | **Air/Soil Volatiles Pathway Score** | x | **Air/Soil Volatiles Human Health Hazard Score** | x | **Air/Soil Volatiles Human Receptor Score** | **/10,000** |
| **Air/Soil Volatiles[2] Ecological Score** | = | **Air/Soil Volatiles Pathway Score** | x | **Air/Soil Volatiles Ecological Hazard Score** | x | **Air/Soil Volatiles Ecological Receptor Score** | **/10,000** |
| **Air/Soil Dust[1] Human Health Score** | = | **Air/Soil Dust Pathway Score** | x | **Air/Soil Dust Human Health Hazard Score** | x | **Air/Soil Dust Human Receptor Score** | **/10,000** |
| **Air/Soil Dust[2] Ecological Score** | = | **Air/Soil Dust Pathway Score** | x | **Air/Soil Dust Ecological Hazard Score** | x | **Air/Soil Dust Ecological Receptor Score** | **/10,000** |

[1] **The higher of these two scores is used in the final computation.**
[2] **The higher of these two scores is used in the final computation.**

**Figure 2.** Algorithm to Calculate DPM Scores (22:2-7)

scores for the air/soil pathways are used to calculate the final DPM score (22:2-7).

Calculating the Final Score. Six pathway-hazard-receptor subscores are combined for the final score. The three human health receptor subscores are weighted five times more than the ecological receptor subscores. These weighing factors reflect the general indication of concern in national environmental regulatory policy regarding the relative importance of human health versus ecological risks (22:2-9).

The root-mean-square methodology is use to combine the subscores to generate a final relative risk score. The algorithm for computing the final score is shown in Appendix A on page 73. The root-mean-square method is an exponential algorithm. The algorithm results in a high score when a score for a single pathway-hazard-receptor score is high. If additional subscores are high the final score increases but not linearly. This methodology increase the importance of a single high pathway-hazard-receptor subscore on the final risk score (21:2-9,2-10).

## Measure Change in Relative Risk

Remedial actions at IRP sites typically involve reducing the volume of the contaminants and/or reducing the potential for the contaminants to be transported. As progress is made towards cleaning up a site, input parameters to the DPM related to the volume and potential

transport of the contaminants will change. The DPM score should reflect a change in relative risk as inputs for contaminant levels and transport pathways are changed.

Forty-eight AF IRP sites that were scored using the latest version of the automated DPM (ADPM92) were selected as sample sites for this study. The sites were scored by the IRP project managers at the respective bases using data representative of the site conditions prior to any remedial action. These sites were selected because the inputs to generate the scores were reviewed by HQ USAF/CEVR to insure Quality Control (QC) standards have been met.
HQ USAF/CEVR provided the computerized ADPM92 data files for the sample sites used in the research (20).

To evaluate the DPM's application as tool to assess reduced risks, the following investigative objectives were carried out:

1. Identify the input variables to the DPM that can be changed or affected by remedial actions.
2. Rescore the sample sites by changing the variable input parameters to reflect environmental conditions after remedial actions are taken.

<u>Identify Inputs That Can Be Changed</u>. The DPM has approximately 100 input parameters to calculate a risk score for an IRP site. The first step will be to examine the input parameters and separate them into two categories. One category is parameters that the input value cannot be affected by remedial actions. Examples of this category

will include input values related to climate, demographics, and geology at a site. The second category is made up of the parameters that can be affected by remedial efforts such as the amount of contaminants or the activity at a site.

There were two input parameters that could not be obviously placed into one of the two categories above. The two parameters are the flooding potential in the surface water pathway section and the groundwater use parameters in the human health receptors for groundwater pathways section.

For scoring the flooding potential at a site the ADPM92 users manual states that:

> Flooding potential is a measure of the potential for contaminants to be transported by flood waters. Flooding potential is measured by the frequency (observed or estimated) of inundation due to stream flooding, coastal flooding, high lake levels, or other causes. (21:23)

The user's manual and the automated version of the DPM suggest this input parameter should strictly be related to the site's location in a flood plain 921:23). Since the regional flood plains likely would not be changed by remedial efforts this would not allow changing the input for the flooding potential. However, remedial measures could be taken to eliminate the potential for contaminants to be transported as a result of flooding. For this research the input for flooding potential for the sample sites rescored was set to the lowest potential for contaminant transport as a result of flooding.

The groundwater use of the aquifer parameter is used to evaluate the level of susceptibility of humans ingesting contaminated groundwater (21:90). Remedial measures often include providing an alternate water source to a population that is using groundwater from a contaminated aquifer. Although the intended measure (the population using the groundwater) would change, there has been no progress made toward improving the environmental conditions at the site. The groundwater use parameter was not selected to be changed since the objective is to measure progress based on improvements in environmental conditions.

The following is a list of the parameters that were identified and selected as the input variables to the DPM that could be changed by remedial actions.

1. The surface erosion potential for the surface water pathway.
2. Flooding potential for the surface water pathway.
3. The site activity for the air/soil dust pathway.
4. The waste containment effectiveness factor for each of the four pathways.
5. The waste quantity factor for each of the four pathways (when applicable).

The ability or appropriateness to change the waste quantity factor is different for various types of sites. The waste quantity factor is related to the amount of contaminant(s) that is estimated to be present for landfill, surface impoundment, and Underground Storage Tank (UST)

sites. This value can be changed by remedial actions. The other case is for spill and Fire Training Area (FTA) sites where the waste quantity factor is a descriptive characteristic of the site that should not be changed.

The waste quantity factor for FTAs is the length of time the site was used as a fire training facility. This cannot be changed by remedial actions. The waste quantity factor for spill sites is the amount of contaminant(s) involved in the spill. Although the contaminants can be removed by remedial actions, the amount of contaminant involved in the spill cannot be changed. The input values for the waste quantity factors for the FTA and spill site were not identified as parameters to be changed for rescoring the sample sites.

Rescore IRP Sites. The purpose for rescoring the sites is to demonstrate the DPM's sensitivity to the input parameters that can be affected by remedial efforts. Each site was rescored by changing the variable input parameters to reflect environmental conditions after remedial actions have taken place. Each variable parameter was changed to the best possible environmental condition considered by the DPM for the parameter. The DPM data and the results of rescoring the 48 sample sites are provided in Table 1 on pages 34 and 35. Although the remedial actions actually chosen for IRP sites may not result in achieving the best possible scenario for every parameter, the DPM rescore

Table 1
DPM Rescore Data

| Base | Site Type | Original Score | Rescore | Change |
|---|---|---|---|---|
| Kelly | Landfill | 46.0 | 5.6 | 40.4 |
| Wright-Pat | Landfill | 61.8 | 6.2 | 55.6 |
| Kelly | Spill | 48.0 | 23.1 | 24.9 |
| Kelly | FTA | 36.2 | 19.4 | 16.8 |
| Tinker | UST | 44.2 | 7.9 | 36.3 |
| Tucson | Spill | 10.6 | 3.3 | 7.3 |
| England | UST | 19.3 | 4.7 | 14.6 |
| MacDill | Spill | 21.5 | 5.7 | 15.8 |
| England | Spill | 29.4 | 15.3 | 14.1 |
| Mt. Home | FTA | 24.1 | 14.4 | 9.7 |
| Davis Monthan | Waste Piles | 20.5 | 3.4 | 17.1 |
| Tinker | Waste Piles | 9.0 | 1.6 | 7.4 |
| Tinker | Landfill | 27.2 | 2.7 | 24.5 |
| Tinker | UST | 37.9 | 5.8 | 32.1 |
| Kelly | Landfill | 41.7 | 5.4 | 36.3 |
| Kelly | Landfill | 26.9 | 5.0 | 21.9 |
| Kelly | Surface Impoundment | 28.7 | 4.9 | 23.8 |
| Wright-Pat | Landfill | 60.7 | 6.5 | 54.2 |
| Wright-Pat | Landfill | 51.1 | 6.4 | 44.7 |
| Kelly | Surface Impoundment | 23.7 | 4.2 | 19.5 |
| Tinker | UST | 20.6 | 6.0 | 14.6 |
| Kelly | Spill | 25.9 | 13.5 | 12.4 |
| Tinker | Landfill | 10.6 | 1.6 | 9.0 |
| Tinker | Landfill | 30.1 | 3.5 | 26.6 |
| Vance | Surface Impoundment | 17.0 | 3.1 | 13.9 |
| Vance | FTA | 30.6 | 19.1 | 11.5 |
| Vance | UST | 38.6 | 6.0 | 32.6 |
| Vance | UST | 38.5 | 6.0 | 32.5 |
| Vance | UST | 18.1 | 5.9 | 12.2 |
| Vance | UST | 31.1 | 5.9 | 25.2 |
| Vance | Landfill | 9.5 | 2.0 | 7.5 |
| Columbus | Spill | 41.7 | 19.6 | 22.1 |
| Lackland | Spill | 23.1 | 12.4 | 10.7 |
| Sheppard | Surface Impoundment | 6.7 | 1.4 | 5.3 |
| Beale | Landfill | 40.8 | 5.2 | 35.6 |
| Beale | UST | 38.3 | 5.7 | 32.6 |
| Vandenberg | FTA | 19.8 | 11.3 | 8.5 |
| Vandenberg | Spill | 39.9 | 21.1 | 18.8 |
| Vandenberg | Surface Impoundment | 16.3 | 4.0 | 12.3 |
| Vandenberg | Spill | 4.7 | 1.8 | 2.9 |
| Malmstrom | UST | 5.6 | 0.6 | 5.0 |
| Charleston | Landfill | 10.0 | 1.4 | 8.6 |
| Charleston | Other | 5.2 | 1.3 | 3.9 |

Table 1 (cont.)
DPM Rescore Data

| Base | Site Type | Original Score | Rescore | Change |
|---|---|---|---|---|
| Andrews | FTA | 29.1 | 11.8 | 17.3 |
| Andrews | Landfill | 28.3 | 5.6 | 22.7 |
| Andrews | Spill | 23.1 | 10.9 | 12.2 |
| McGuire | Spill | 32.3 | 11.1 | 21.2 |
| AF Academy | Landfill | 47.8 | 4.8 | 43.0 |

represents the maximum amount of reduction in risk possible for a site.

In order to demonstrated that the DPM can used to measure risk reduction, the risk scores should be reduced when the input parameters identified in the previous section are changed. It would be expected that for higher original DPM risk scores the would be a greater risk reduction potential. A statistical analysis of relationship between the original DPM scores and the data generated by rescoring the sample sites is discussed in Chapter VI.

This effort is simply to determine if a change in relative risk can be measured using the DPM. It is not the focus of this research to evaluate the methods used by the DPM to calculate relative risk at contaminated sites or to validate the results of the model.

## V. Multi-Criteria Evaluation of Progress

Human reasoning desires to get as close as possible to an ideal situation or one that is better than its alternatives (14:164).

> Although it is difficult to determine the exact performance of a facility [or environmental] system, it may be easier to define a system's performance [or accomplishments] as "better" than another's. The performance therefore is relative, imprecise, and "fuzzy". . . . The relative distance from an imaginary optimum or maximum value of the fuzzy set can be understood in relative terms of far, farther, or close and closer. By using relative descriptions of distance, it is possible to arrive at a value that is "close" to the optimum. (14:164)

Quantitative and qualitative measures of progress can be expressed in relative terms for the various factors used to assess progress. Relative or ordinal measurements only determines that one variable for a factor used to measure progress is greater than or less than another variable (10:173). The Displaced Ideal Model (DIM) incorporates the ability to take relative measurements of factors that indicate progress and relate them to the ideal solution (14:163-164). The DIM was selected to rank the accomplishments of the IRP using risk data and administrative data such as the site closure status.

### Displaced Ideal Model (DIM)

The DIM is a variant of a distance based model where the alternatives are compared to a idea reference point (14:179). As discussed in the previous section the

variations in MCDM techniques depend on how the factors or attributes are weighted. The DIM uses two considerations in assigning weights to each factor used to evaluate the alternatives:

1. the amount of information that is contributed by a factor, and
2. the decisions makers strategic weighing of the factors (14:165).

The amount of information provided by a given factor is determined by Zeleny's adaptation of entropy (29:190). Entropy is defined by Webster as:

> A measure of the randomness, disorder, or chaos in a system specified by the relationship of $S = k\ln P + c$, where S is the value of the measure for a system in a given state, P is the probability of occurrence of that state, and k is a fixed and c is an arbitrary constant. (28:457)

The measure of entropy for a given factor is inversely proportional to the amount of information provided by the factor. When the measure of entropy is large the amount of information provided by that factor is small. Conversely, when the entropy for a factor is small the amount of information provided is large (14:178-179). "The principles of the 'displaced ideal' and 'entropy' are used to determine the effect of the spread of values within each criteria across all of the criteria" (14:179).

The values for the weights generated using entropy to determine the dominate factor are multiplied by the weights provided by the decision maker for each factor. If there is

no dominant factor the user's weighing of the factors has a larger influence of the results of evaluating the alternatives. When the user does not differentiate between the factors (weights them all the same) the model is strictly dependant on the principles of entropy assign the weights (14:165).

Combining the weights generated by the model with the user's weighing of the factors allows the user to adjust the model to meet various strategic applications. It also allows the results of the model to be validated in the sense that it measures the user's or expert's preferences with sufficient accuracy (29:195-198).

Relative Rank of Progress for IRP Sites

The DIM is based on Zeleny's adaptation of entropy to assess the amount of information an attribute provides (29:187-197). The entropy and DIM principles are used to determine if certain factors are dominant in the amount of information they provide with respect to other factors. The DIM weights the factors according to the relative amount of information a factor provides in relation to the other factors. The users weighing of the factors are combined with weights generated by the DIM. When there is a lack of a dominating factor the model relies more heavily on the users weighing of the factors (14-165).

The entropy process and the DIM algorithm developed by Zeleny used to rank progress for the sample sites in this

research is described by the following steps (14:180-182; 29:197):

1. Enter each alternative or set of data describing an IRP site as line items or rows into a table: $x_{i,j}$

   Where: $i$ = number of sites or alternatives or rows, and

   $j$ = number of factors or columns.

2. Find the optimum value for each factor: $\max_j$

3. Find the percentage of the optimum value for each factor of each site: $d_{i,j}=\frac{x_{i,j}}{\max_j}$

4. Sum the percentage of each optimum value ($D_j$) for each factor: $D_j=\sum_i d_{i,j}$

5. Find the relative distance of each value ($k_{i,j}$) from the optimum value: $k_{i,j}=|1-d_{i,j}|$

7. Find the distance factor ($X_{i,j}$) by dividing the percentage of the optimum value by the summed total for the respective factor: $X_{i,j}=\frac{d_{i,j}}{D_j}$

8. Find the "entropy" for each factor for each site ($e_{i,j}$) using the natural log function:

$$e_{i,j}=(X_{i,j})\cdot -\ln(X_{i,j})$$

9. Find the entropy for each of the factors ($edi_j$) by dividing the sum of the entropy for each site by the maximum entropy value ($e_{max}$) : $edi_j=[\frac{1}{e_{max}}]\cdot\Sigma e^{(j)}$

Where: $e_{max}=\ln(n)$, $n$ = number of sites.

10. Calculate the weights representing the amount of information provided by each factor ($\lambda$) by the following equation: $\lambda_j=\frac{1}{n-\Sigma edi_j}\ [1-edi_j]$

11. The final weights ($\lambda i$) are calculated by the following equation: $\lambda i_j=\frac{\lambda_j\cdot w_j}{\sum_j \lambda_j\cdot w_j}$

Where: $w_j$= the weight provided by the user for each factor.

12. The final weights ($\lambda i_j$) are then multiplied by the relative distance values ($k_{i,j}$) for the respective factors for each site: $K_{i,j}=\lambda i_j\cdot k_{i,j}$

13. The relative rank order is then calculated by summing the values of K for each site:

$$rank=\sum_j K_{i,j}$$

The output will be a number between zero and one for each site. The output represents the closeness of each site to the optimum or idea alternative. If each of the factors considered for a site was the optimum value for the

respective factors the output would be zero or an optimum solution. Likewise the higher the output, the further the site is from the optimum situation. This provides a relative ranking of the sites according to significance of accomplishments as a result of the actions taken.

The DIM was used to combine the risk data generated by the DPM with the measure of progress currently used by the AF which is whether the site has been closed out. Input of risk data consisted of three measures related to risk: the original DPM score, the measure of potential for risk reduction, and the amount risk reduction achieved at a site. The results of using these criteria and the DIM to rank the progress for the sample sites is presented in Chapter VI.

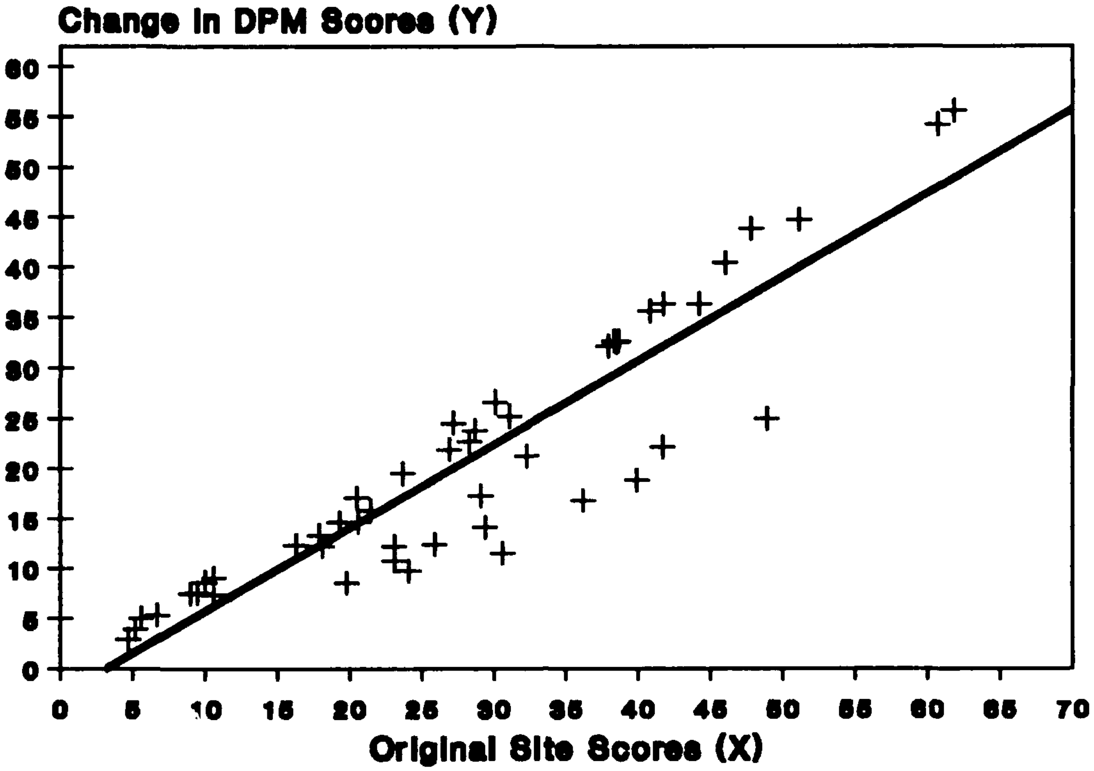
## VI. Analysis and Evaluation of Results

### Analysis of DPM Rescore Data

In order to demonstrated that the DPM can used to measure risk reduction, the risk scores should be reduced when the input parameters identified in Chapter IV are changed. Each site was rescored by changing the variable input parameters to determine the maximum amount of risk reduction possible for each sample site. It would be expected that for higher original DPM risk scores there would be a greater risk reduction potential.

To determine if there is any relationship between original DPM scores and the results of rescoring the sites a regression analysis was performed. As the original DPM scores increase the amount of potential risk reduction by remedial actions also increases. This was determined by statistical evaluation of the relationship between the original site scores and the amount of potential change in the DPM score.

There is a nondeterministic linear relationship that can be described by the equation $Y = A(X) + B$. The independent variable (X) is the original site score and the dependant variable (Y) is the difference between the original score and the rescore results for a site. A plot and regression analysis of the data and for all of the sample sites is shown in Figure 3. Statistical tests (student t-test and F-test) can be used to determine the




Y = 0.8259(X) - 2.4239

Correlation Coefficient : 0.9206

Standard Error : 5.2392

**Figure 3.** DPM Rescore Data for All Sites

significance of the correlation of the two variables determined by the regression analysis (1). In all cases the correlation of the two variables exceeded the 95 percent confidence interval.

Although there was a reasonably good correlation between the original scores and the rescores for all of the

sites considered together, a more precise correlation can be shown by evaluating the data by site type. As discussed in the previous section, the manner in which the waste quantity parameter of the DPM was input was different for various types of sites. This had an effect on the amount DPM scores could be reduced as the original scores increased.

When the waste quantity factor is changed to zero to rescore the sites (for the landfills, surface impoundments, and USTs) the DPM rescore values approach a constant value. For the FTAs and Spill sites where the waste quantity input value is not changed, the rate of increase for potential risk reduction as the original DPM score increases is lower. Although there are different relationships there is a good correlation between original scores and the potential risk reduction for each of the site types.

The difference in the relationships for various types of sites is evident from the slope of the plot of the original scores versus the rescore values by site type (shown in Figure 4). This difference is also evident from a regression analysis of the data for the various site types. The following provides a brief description of the analysis of the DPM rescore data by site type.

<u>Landfill Sites</u>. Fourteen landfill sites were included in the 48 sample sites. The landfill sites had the largest range of original scores, from 9.5 to 61.8, and the smallest range of rescore values, from 1.4 to 6.5. The plot of the original scores versus the rescore values (Figure 4)

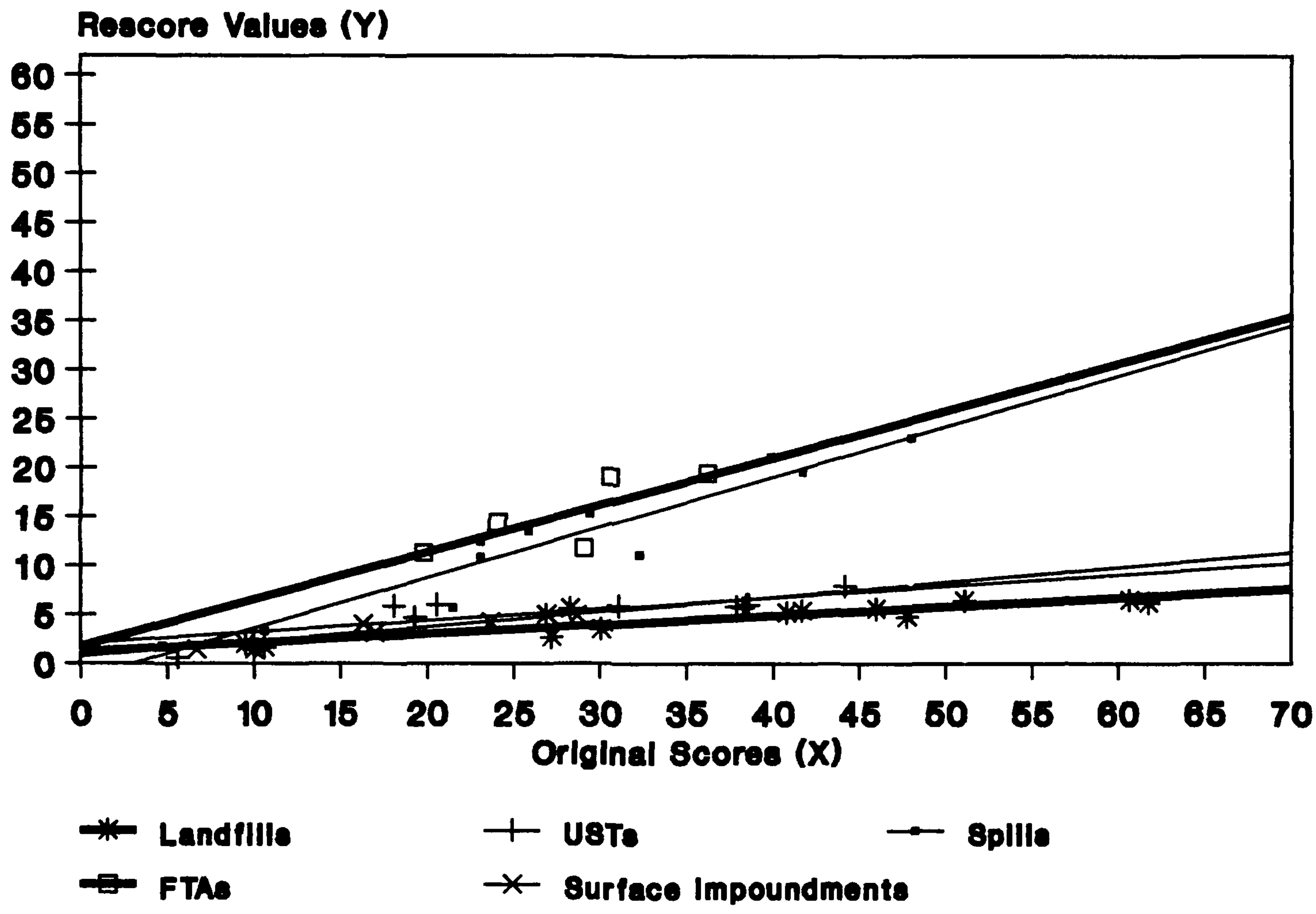



**Figure 4.** Original DPM Scores versus Rescores

shows that there is the largest potential change in DPM scores as the original scores increase. The DPM rescore data for the landfill sites is shown in Figure 5. The regression analysis of the data for the landfills show the highest level of correlation between the original scores and the rescores. The rescore values for all landfill sites approach a constant score of approximately six.

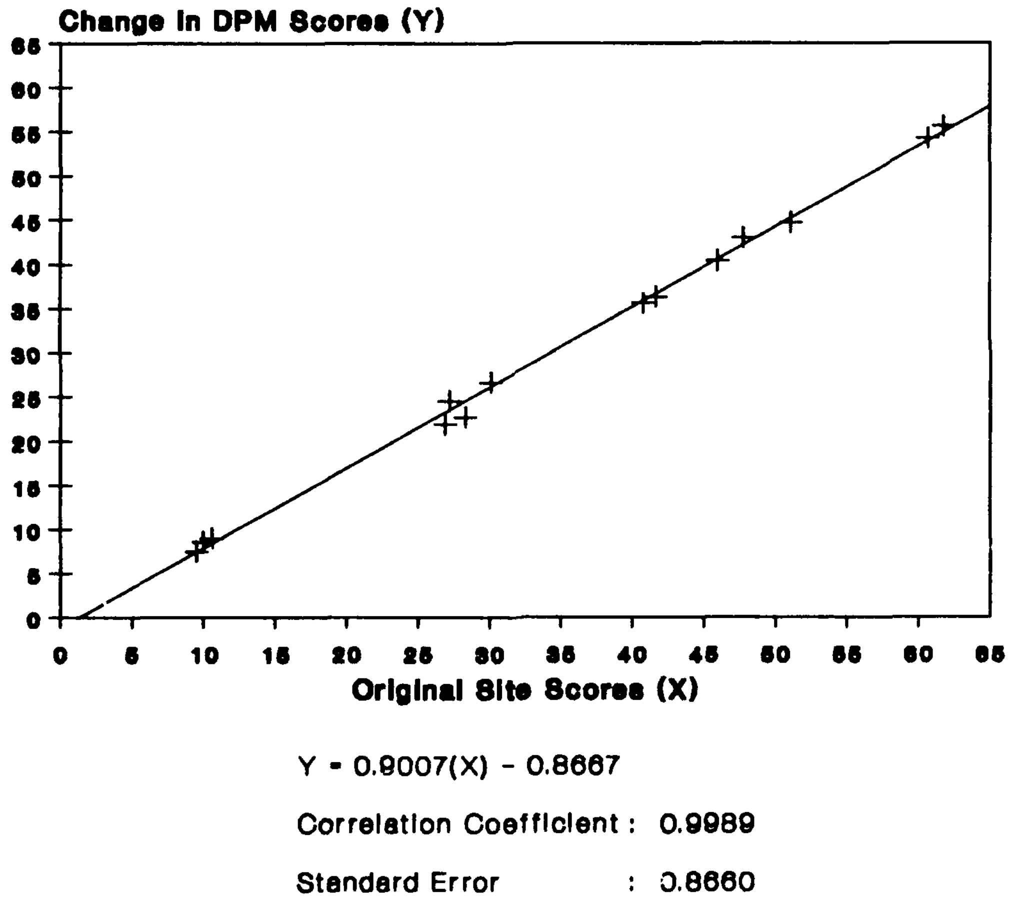
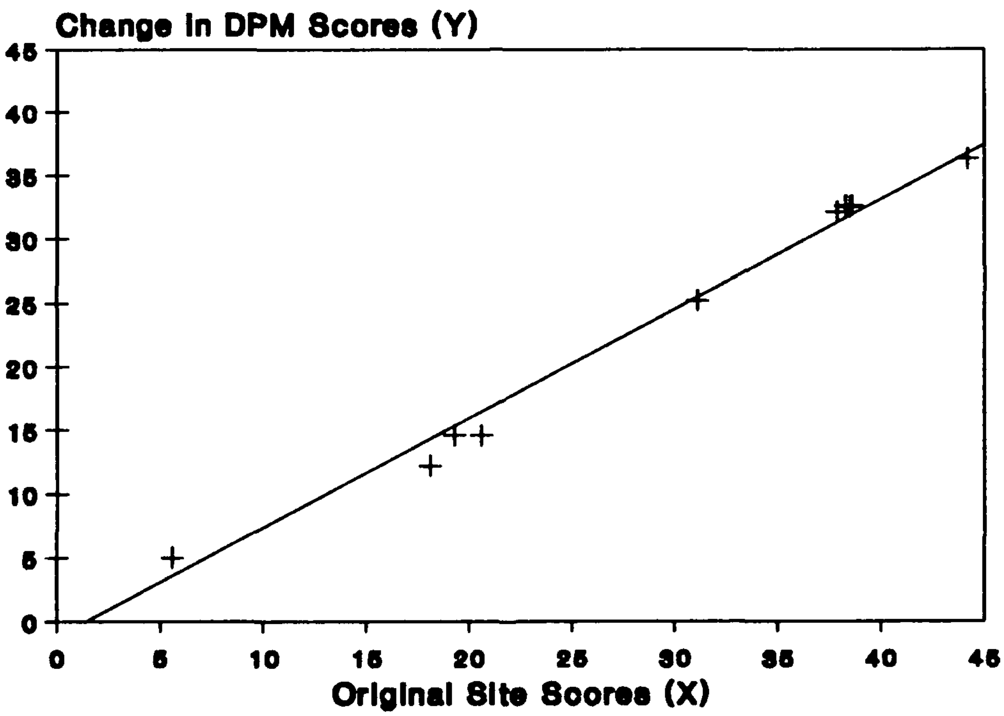



**Figure 5.** DPM Rescore Data for Landfill Sites

UST Sites. Ten of the 48 sample sites rescored were UST sites. There original DPM scores ranged from 5.6 to 44.2 and the rescore values ranged from 0.6 to 7.9. The rescore values for the UST site appears to approach a constant value of approximately six. A regression analysis of the correlation between the original scores and the potential risk reduction is shown in Figure 6. The high correlation coefficient value and low standard error




$Y = 0.8584(X) - 1.1932$

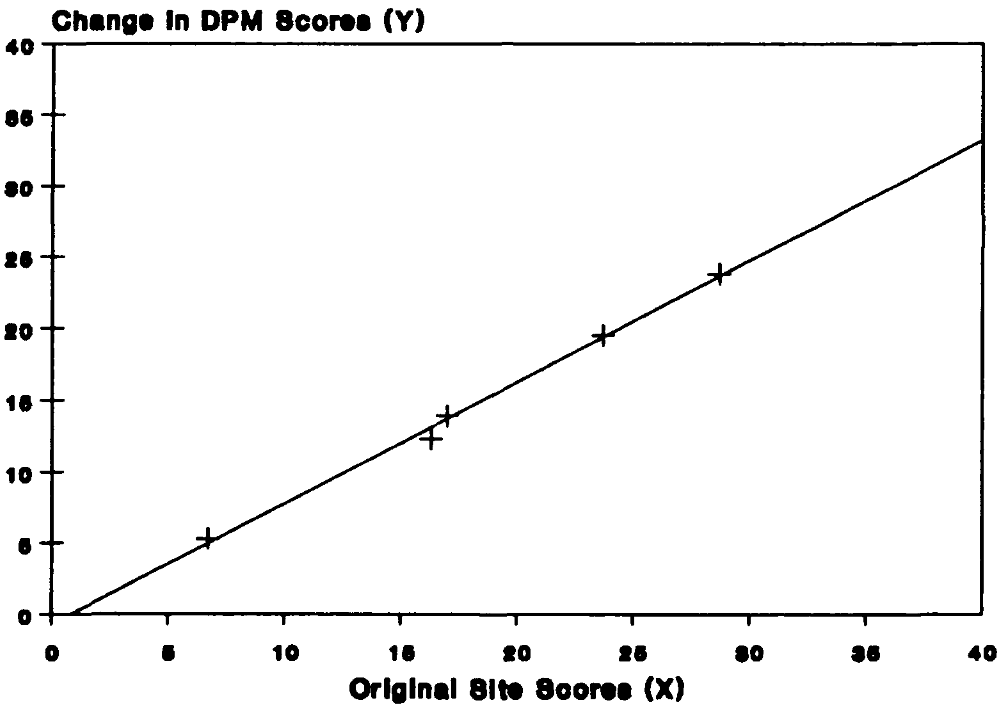
Correlation Coefficient : 0.9955

Standard Error : 1.2768

**Figure 6.** DPM Rescore Data for UST Sites

indicate that there is good correlation between the original site score and the amount of potential risk reduction.

Surface Impoundment Sites. There were five surface impoundment sites that range from 6.7 to 28.7 for original DPM scores. The rescore values range from 1.4 to 4.9. The regression analysis that describes the relationship between the DPM scores and the amount of potential risk reduction for the surface impoundment sites is provided in Figure 7.



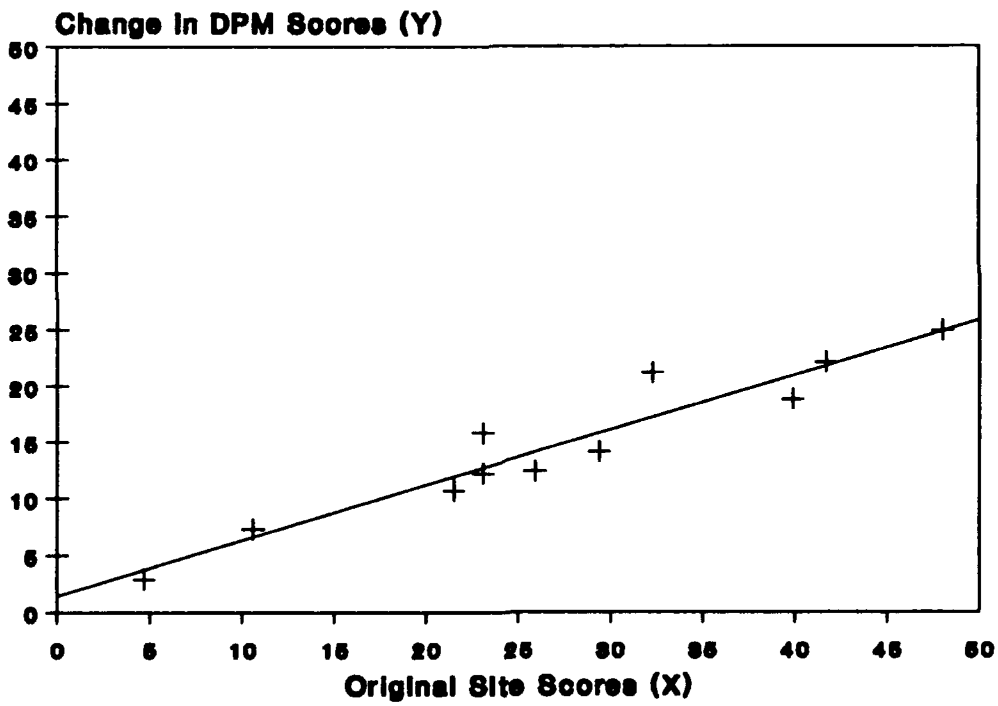

Y = 0.1715(X) - 0.2915

Correlation Coefficient : 0.9696

Standard Error : 0.5134

**Figure 7.** DPM Rescore Data for Surface Impoundment Sites

Spill Sites. Eleven of the 48 sample sites rescored were spill sites. There original DPM scores ranged from 4.7 to 48.0 and the rescore values ranged from 2.9 to 24.9. The change in the amount the risk can be reduced as the original DPM score increases is smaller for spill sites since the waste quantity factor was not be reduced. An analysis of the correlation between the original scores and the potential risk reduction is shown in Figure 8.



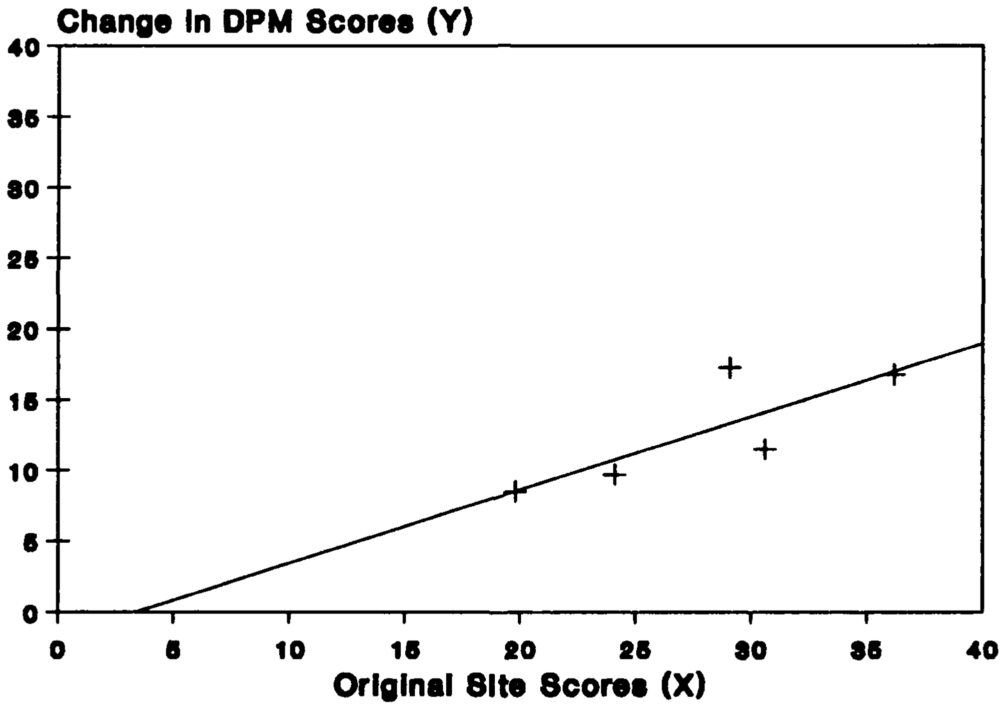

Y = 0.5003(X) + 1.0175

Correlation Coefficient : 0.9616

Standard Error : 2.1955

**Figure 8.** DPM Rescore Data for Spill Sites

FTA Sites. There were five FTA sites that range from 19.8 to 36.2 for original DPM scores. The rescore values range from 8.5 to 16.8. The regression analysis that describes the relationship between the DPM scores and the amount of potential risk reduction for the FTA sites is provided in Figure 9. The correlation between the original score and rescore values for the FTAs also exceeds the 95 percent confidence interval.




Y = 0.4684(X) - 0.2812

Correlation Coefficient : 0.9382

Standard Error : 2.4580

**Figure 9.** DPM Rescore Data for FTA Sites

Evaluation of the Methods Developed to Assess Progress

To evaluate the methods developed to compare the accomplishments of actions taken at IRP sites, a sample test case was used to demonstrate the results to expert IRP managers. Personal interviews with the IRP managers were used to compare the results of the methods developed with their views on how progress should be measured. A list of the IRP managers that participated in the sample test case is provided in Appendix B on page 74.

Twenty sites from the 48 sample sites that were rescored were selected to demonstrate the DIM ranking of the sites. The test case developed to demonstrate the DIM consisted of five sites from each of four different types of sites. The sites were selected so that the widest range of site status scenarios could be represented. This was done by selecting two high scores, two low scores and one mid range score from each of four site types. The data used for the potential risk reduction achieved and the site closure factors were made so that a wide variety of site status scenarios would be represented. The sample site data used to demonstrate the DIM along with a description of the test case data is provided in Appendix C on page 75.

Experts' Ranking of Progress. The experts were asked to rank the sample sites according to their evaluation of progress using the sample data provided. There is a reasonably good agreement among the experts' on ranking the sites where the most and least progress has been made.

Table 2 on page 53 shows how the sites are ranked by each of the experts. The rank order for the sites in Table 2 is listed in the order of the total ranking which is the combined scores from all three experts.

When each of the managers were interviewed they indicated the most significant criterion they used for ranking the sites was the amount of risk reduced at a site. Two of the IRP managers, Mr. Kneeling and Mr. Ratliff used the amount of risk reduced as the primary criterion to rank the sites. However, they used two different methods to consider the risk reduction. Mr. Ratliff ranked the sites using the change in risk achieved factor. When two sites were equal, as in the case of sites P and Q or sites K and S, he then used the site closed factor to rank one site over the other (23).

Mr. Kneeling ranked the sites by assigning each site to one of four categories representing the level of threat using the original DPM score. DPM scores over 40 are considered a high threat, scores between 20 and 40 are a moderate threat, scores between 10 and 20 are a low threat and scores below 10 are considered no threat. He then looked at which category the sites would be in as a result of the actions taken. The sites which moved from the high threat to the no threat categories were ranked the highest. The sites where there was a less significant or no change from one category to another were ranked lower accordingly. When there was no change from one category to another

## Table 2
## Results of the Experts' Ranking of Progress

| RANK | SITE ID | INDIVIDAUL EXPERT'S RANKING | | | TOTAL RANK | REDUCED RISK | CLOSED |
|---|---|---|---|---|---|---|---|
| | | GEIL | KNEELING | RATLIFF | | | |
| 1 | SITE C | 1 | 3 | 2 | 6 | 36 | Y |
| 2 | SITE A | 2 | 4 | 1 | 7 | 53 | Y |
| 3 | SITE P | 3 | 2 | 3 | 8 | 33 | Y |
| 4 | SITE Q | 4 | 1 | 4 | 9 | 20 | N |
| 5 | SITE F | 7 | 7 | 6 | 19 | 15 | N |
| 6 | SITE K | 6 | 5 | 8 | 19 | 27 | N |
| 7 | SITE B | 9 | 6 | 5 | 21 | 11 | N |
| 8 | SITE H | 5 | 8 | 10 | 23 | 10 | Y |
| 9 | SITE N | 8 | 9 | 11 | 28 | 15 | Y |
| 10 | SITE S | 10 | 12 | 7 | 29 | 9 | Y |
| 11 | SITE D | 13 | 10 | 12 | 35 | 12.5 | Y |
| 12 | SITE R | 12 | 15 | 9 | 36 | 7 | N |
| 13 | SITE I | 11 | 11 | 15 | 37 | 9.5 | N |
| 14 | SITE G | 15 | 13 | 13 | 41 | 9.5 | N |
| 15 | SITE M | 18 | 14 | 14 | 46 | 8.5 | N |
| 16 | SITE T | 14 | 16 | 16 | 46 | 0 | Y |
| 17 | SITE O | 16 | 18 | 19 | 53 | 0 | Y |
| 18 | SITE L | 17 | 17 | 20 | 54 | 0 | Y |
| 19 | SITE E | 19 | 19 | 17 | 55 | 0 | Y |
| 20 | SITE J | 20 | 20 | 18 | 58 | 0 | Y |

Mr. Kneeling considered the actions at sites with low or no threat to be the least significant. Mr. Kneeling did not consider the site closed criterion at all to rank the progress for the sites (15).

Ms. Geil used a qualitative assessment of the data provided. She thought that there is no way to consider progress strictly quantitatively, there must be some qualitative assessment by expert managers. She ranked the site using three primary considerations: the amount of risk reduced, the residual risk at a site, and whether the site has been closed. Instead of using HQ USAF/CEV guidance for determining a 'yes' or 'no' for site closed she suggested there needs to be a qualitative assessment of the regulatory and community relationships related to IRP actions (11).

Displaced Ideal Model (DIM) Results. To demonstrate the DIM, the users' input for weighing each of the factors were set to be equal (a weight of .25 for each of the four factors considered). This allowed the weighing of each factor to be assigned according to the amount of information provided by each factor as determined by the entropy function. The weights assigned to each factor using the entropy function are as follows: original DPM score 10.85, change in risk possible 17.39, change in risk achieved 32.38, and site closed 39.17.

Relying on the entropy function alone to assign weights for the factors did not result in an accurate simulation of

the experts' interviewed ranking of the sites. The results of using the DIM to rank the sample sites are shown in Table 3 on page 56. Although the DIM accurately simulated the experts' ranking for the top three sites, the overall accuracy was poor. This was due to the relatively high weight given to the site closed criterion and low weight given to the change in risk when compared to expert's consideration of these two factors.

The users input for weighing of each of the factors can be adjusted so that the model can be used for various users management strategies. By trial and error the user input weights were adjusted so that the DIM better simulated the results of the experts' ranking of the sites. The user input weights assigned to each factor are as follows: original DPM score 20, change in risk possible 10, change in risk achieved 65, and site closed 5. The results of using the DIM with the adjusted user weights is shown in Table 4.

By combining the users' input weight described above with the weights generated by the entropy function the final weights are 8.02, 6.43, 78.3, and 7.24 respectively. These weights more closely represent the experts' consideration of the factors when they were asked how they went about ranking the sites. The results show that the DIM can be used to simulate the experts' ranking of the site with reasonable accuracy.

Table 3
DIM Ranking of Progress

| Rank | Site ID | Experts' Rank |
|---|---|---|
| 1 | Site A | 2 |
| 2 | Site C | 1 |
| 3 | Site P | 3 |
| 4 | Site S | 10 |
| 5 | Site H | 8 |
| 6 | Site N | 9 |
| 7 | Site T | 16 |
| 8 | Site D | 11 |
| 9 | Site L | 18 |
| 10 | Site O | 17 |
| 11 | Site B | 7 |
| 12 | Site E | 19 |
| 13 | Site J | 20 |
| 14 | Site Q | 4 |
| 15 | Site F | 5 |
| 16 | Site K | 6 |
| 17 | Site R | 12 |
| 18 | Site G | 14 |
| 19 | Site M | 15 |
| 20 | Site I | 13 |

Table 4
Adjusted DIM Ranking of Progress

| Rank | Site ID | Experts' Rank |
|---|---|---|
| 1 | Site A | 2 |
| 2 | Site C | 1 |
| 3 | Site P | 3 |
| 4 | Site Q | 4 |
| 5 | Site B | 7 |
| 6 | Site F | 5 |
| 7 | Site S | 10 |
| 8 | Site K | 6 |
| 9 | Site H | 8 |
| 10 | Site N | 9 |
| 11 | Site R | 12 |
| 12 | Site D | 11 |
| 13 | Site G | 14 |
| 14 | Site T | 16 |
| 15 | Site M | 15 |
| 16 | Site I | 13 |
| 17 | Site L | 18 |
| 18 | Site O | 17 |
| 19 | Site E | 19 |
| 20 | Site J | 20 |

## VII. Conclusion

### Overview

Measuring the number or percent of sites closed does not reflect what has been done to improve the environmental conditions at IRP sites (3:144). At many of the closed sites no remedial actions have been taken at all. Currently the AF has no way to compare the accomplishments at the most significant cleanup efforts (at the worst sites) to sites where no remedial action is required. To properly manage the IRP the AF needs to be able to assess progress based on tangible environmental improvements.

An important part of evaluating progress toward protecting human health and the environment is the assessment of risk reduction as a result of cleanup actions. The AF currently uses the DPM to assist in setting priorities for funding remedial actions based on the relative risk at IRP sites. The DPM provides a numerical score representing the relative potential risk based on the environmental conditions at a site.

The purpose of this study was to develop a method to use risk reduction as a criterion to assess progress for the IRP. Once a method is available to quantify reduction in risk, the risk data can be combined with other factors to rank progress using various multi-criteria evaluation techniques.

The following section summarizes findings of using the DPM to measure reduced risk and using the DIM to rank progress. The last two sections discuss the application of the research and recommendations for further development of methods to use a risk based approach for managing the IRP.

## Summary of Findings

Using the DPM to Quantify Risk Reduction. The DPM calculates relative risk by considering the type and amount of contaminant(s) along with the potential transport pathways and the potential receptors. As progress is made toward cleaning up a site, input parameters to the DPM related to the volume and potential transport of the contaminants change. Rescoring the DPM to represent conditions after remedial actions at sample sites shows a reduction in relative risk. Using the DPM to measure risk before, during, and after remedial actions can provide an indicator of progress based on improvements in environmental conditions at IRP sites.

Using the DIM to Rank Progress. By comparing the results of the expert's to the results of the DIM it was determined that the DIM could be used to simulate the expert's ranking of progress. The DIM needs to be adjusted and tested to ensure that it accurately reflects the users' specific concerns or management strategies related to measuring progress for the IRP.

Applications for Managing the IRP

An important part of the personal interviews was to determine if there is an application for methods developed to provide a more meaningful assessment of progress to manage the IRP. Each of the managers interviewed believe that a risk based assessment of progress is more appropriate than using administrative milestones such as the number of sites closed. Each of the experts indicated that there are potential applications they could foresee for the methods developed in this research. However, all of the experts feel that the most useful application would involve using risk reduction data along with cost to rank progress or set priorities for the IRP.

There are two specific potential applications for using a risk based assessment of progress that were brought up in the expert interviews. The first application is to provide managers a method to compare IRP projects, base programs, or MAJCOM programs based on their accomplishments toward improving environmental conditions (15).

The current methods of evaluating IRP projects or programs give credit only when sites can quickly be closed. Typically only sites where no or very insignificant improvements of environmental conditions have been made have been closed. At many of the closed sites no remedial actions have been taken at all. There is no way of differentiating the amount of significant improvements in environmental conditions as a result of the actions taken at

a site. A risk based assessment provides a method to show progress at the most significant cleanup efforts (at the worst sites) that take many years to complete (18). By considering the cost along with the amount of risk reduction the managers would be able to consider the "bang for the buck" for the actions taken at IRP sites (18).

The second potential application of the methods developed was for prioritizing potential cleanup alternatives. The DPM can be rescored for the level of various potential cleanup alternatives. Then the DPM risk reduction data could be used along with estimated cost to prioritize and select remedial alternatives (15;18).

## Recommendations

There will most likely continue to be an increasing level of interest and oversight of environmental cleanup programs such as the IRP. It is important for the AF to be able to show progress toward restoring the environment and eliminating the threat posed by the worst sites. To justify and properly manage resources for the IRP, the AF needs to employ risk based methods to assess progress.

In order to further develop and implement the methods used in this research, test cases using actual data from sites where cleanups are underway should be investigated. The biggest benefit of using data representing actual site scenarios will be to allow considering cost as a factor to consider with the risk data. Cost or "bang for the buck"

would be weighted very heavily for the potential application to measure progress or select remedial action alternatives (15;18). Cost of the remedial action taken was not used as a criterion for this research because no data was available for the sample sites.

A comparison of cleanup actions at the worst sites to sites where little or no action was required to close the site using actual site status data should be investigated. This will require rescoring the DPM for sites where cleanup has taken place to represent the actual level of action taken. This could include sites where the cleanup has not been completed. An original DPM score representing the risk at sites where no remedial actions where required to close the site would also need to be generated. Typically the DPM has only been scored for sites when there is a request for DERA funding to take remedial actions. The actual cost of the actions taken for a limited number of sites should be available to use in the investigation.

Another area that may be investigated is the application of using the DPM to select remedial alternatives at a site. The DPM could be scored to represent several various site conditions that would be a result of the alternative selected. The estimated cost of each of the alternatives along with likelihood of regulatory and/or public acceptance of the action could be considered with the risk data.

## SURFACE WATER PATHWAY

| Detected Releases | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|
| 1. Have contaminants been detected in surface water? If yes, assign score of 100 and proceed to item [10]. If no, assign a score of 0 and proceed to item [2]. | 0 100 | 1 | ___ | 100 |
| **Pathway Characteristics** | | | | |
| 2. Distance to nearest surface water | 0 1 2 3 | 4 | ___ | 12 |
| 3. Net precipitation | 0 1 2 3 | 1 | ___ | 3 |
| 4. Surface erosion potential | 0 1 2 3 | 4 | ___ | 12 |
| 5. Rainfall intensity | 0 1 2 3 | 4 | ___ | 12 |
| 6. Surface hydraulic conductivity | 0 1 2 3 | 3 | ___ | 9 |
| 7. Flooding potential | 0 1 2 3 | 10 | ___ | 30 |
| 8. Sum of items [2] through [7] | | | ___ | 78 |
| 9. Normalized score (item [8] × 100/78) | | | ___ | |
| 10. Waste containment effectiveness factor | | | ___ | |
| 11. Waste quantity factor | | | ___ | |
| 12. Final pathway score for surface water (item [9] × (item [10] + item [11])/2). | | | ___ | |

## GROUND WATER PATHWAY

| Detected Releases | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|
| 13. Have contaminants been detected in ground water? If yes, assign score of 100 and proceed to item [20]. If no, assign score of 0 and proceed to item [14]. | 0 100 | 1 | ___ | 100 |
| **Pathway Characteristics** | | | | |
| 14. Distance to seasonal high ground water from base of waste or contaminated zone and potential for discrete features in the unsaturated zone to "short circuit" the pathway to the water table | 0 1 2 3 4 5 6 | 10 | ___ | 60 |
| 15. Hydraulic conductivity of the unsaturated zone | 0 1 2 3 | 5 | ___ | 15 |
| 16. Infiltration potential | 0 1 2 3 | 5 | ___ | 15 |
| 17. Geochemical properties of the vadose zone | 0 1 2 3 | 5 | ___ | 15 |
| 18. Sum of items [14] through [17] | | | ___ | 105 |
| 19. Normalized score (item [18] × 100/105) | | | ___ | |
| 20. Waste containment effectiveness factor | | | ___ | |
| 21. Waste quantity factor | | | ___ | |
| 22. Final pathway score for ground water (item [19] × (item [20] + item [21])/2) | | | ___ | |

## AIR/SOIL VOLATILES PATHWAY

| Detected Releases | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|
| 23. Have volatile contaminants been detected in ambient air above background levels? If yes, assign score of 100 and proceed to item [32]. If no, assign score of 0 and proceed to item [24]. | 0 100 | 1 | ___ | 100 |
| **Pathway Characteristics** | | | | |
| 24. Have volatile contaminants been detected in surface soil? If yes, assign a score of 3 and proceed to item [25]. If no, assign a score of 0 to items [24] and [34], and proceed to item [35]. | 0 3 | 12 | ___ | 36 |
| 25. Average summer soil temperature | 0 1 2 3 | 2 | ___ | 6 |
| 26. Net precipitation | 0 1 2 3 | 2 | ___ | 6 |
| 27. Wind velocity | 0 1 2 3 | 2 | ___ | 6 |
| 28. Soil porosity | 0 1 2 3 | 2 | ___ | 6 |
| 29. Sum of items [24] through [28] | | | ___ | 60 |
| 30. Normalized score (item [29] × 100/60) | | | ___ | |
| 31. Adjusted pathways score. If item [23] is 100, enter 100. If item [23] is 0 and item [24] is 0, enter 0. If item [24] is not 0, enter value from item [30]. | | | ___ | |
| 32. Waste containment effectiveness factor | | | ___ | |
| 33. Waste quantity factor | | | ___ | |
| 34. Final pathway score for air/soil volatiles (item [31] × (item [32] + item [33])/2) | | | ___ | |

**AIR/SOIL DUST PATHWAY**

| Detected Releases | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|
| 35. Have non-volatile contaminants been detected in ambient air above background levels? If yes, assign score of 100 and proceed to item [44]. If no, assign score of 0 and proceed to item [36]. | 0 100 | 1 | ___ | 100 |
| **Pathway Characteristics** | | | | |
| 36. Have non-volatile contaminants been detected in the surface soil? If yes, assign a score of 3 and proceed to item [37]. If no, assign a score of 0 to items [36] and [46], and proceed to item [47]. | 0 3 | 12 | ___ | 36 |
| 37. Net precipitation | 0 1 2 3 | 2 | ___ | 6 |
| 38. Wind velocity | 0 1 2 3 | 2 | ___ | 6 |
| 39. Days/year > 0.25 mm precipitation | 0 1 2 3 | 2 | ___ | 6 |
| 40. Site activity | 0 1 2 3 | 2 | ___ | 6 |
| 41. Sum of items [36] through [40] | | | ___ | 60 |
| 42. Normalized score (item [41] × 100/60) | | | ___ | |
| 43. Adjusted pathways score. If item [35] is 100, enter 100. If item [35] is 0 and item [36] is 0, enter 0. If item [36] is not 0, enter value from item [42]. | | | ___ | |
| 44. Waste containment effectiveness factor | | | ___ | |
| 45. Waste quantity factor | | | ___ | |
| 46. Final pathway score for air/soil dust (item [43] × (item [44] + item [45])/2) | | | ___ | |

## CONTAMINANT HAZARD–SURFACE WATER

| | Score (circle one) | Result |
|---|---|---|
| 47. Sum of Health Hazard Quotients (from column 9 of the Surface Water Hazard Worksheet for detected releases). | | ___ |
| 48. Human Health Hazard Score (Table G-1). | 0 1 2 3 4 5 6 | ___ |
| 49. Final Health Hazard Score for surface water pathway (item [48] × 100/6). | | ___ |
| 50. Sum of Ecological Hazard Quotients (enter the larger of the sum of column 10 of the Surface Water Hazard Worksheet for detected releases). | | ___ |
| 51. Ecological Hazard Score (Table G-2). | 0 1 2 3 4 5 6 | ___ |
| 52. Final Ecological Hazard Score for surface water pathway (item [51] × 100/6). | | ___ |
| 53. Maximum Health Hazard Score (from column 2 of the Surface Water Hazard Worksheet for non-detected releases). | 0 1 2 3 4 5 6 7 8 9 | Contaminant: ________ |
| 54. Final Health Hazard Score for surface water pathway (item [[illegible]] × 100/9). | | ___ |
| 55. Maximum Ecological Hazard Score (from column 3 of the Surface Water Hazard Worksheet for non-detected releases). | 0 1 2 3 4 5 6 | Contaminant: ________ |
| 56. Final Ecological Hazard Score for surface water pathway (item [55] × 100/6). | | ___ |

## CONTAMINANT HAZARD–GROUND WATER

| | Score (circle one) | Result | |
|---|---|---|---|
| 57. Sum of Health Hazard Quotients (from column 9 of Ground Water Hazard Worksheet for detected releases). | | ____ | |
| 58. Human Health Hazard Score (Table G-1). | 0 1 2 3<br>4 5 6 | ____ | |
| 59. Final Health Hazard Score for ground water pathway (item [58] × 100/6). | | ____ | |
| 60. Sum of Ecological Hazard Quotients (column 10 Ground Water Hazard Worksheet for detected releases). | | ____ | |
| 61. Ecological Hazard Score (Table G-2). | 0 1 2 3<br>4 5 6 | ____ | |
| 62. Final Ecological Hazard Score for ground water pathway (item [61] × 100/6). | | ____ | |
| 63. Maximum Health Hazard Score (from column 11 of the Ground Water Hazard Worksheet for non-detected releases). | 0 1 2 3 4 5 6 7 8 9 | | Contaminant: ________ |
| 64. Final Health Hazard Score for ground water pathway (item [63] × 100/9). | | ____ | |
| 65. Maximum Ecological Hazard Score (from column 12 of the Ground Water Hazard Worksheet for non-detected releases). | 0 1 2 3 4 5 6 | | Contaminant: ________ |
| 66. Final Ecological Hazard Score for ground water pathway (item [65] × 100/6). | | ____ | |

## CONTAMINANT HAZARD–AIR/SOIL VOLATILES

| | Score (circle one) | Result |
|---|---|---|
| 67. Sum of Health Hazard Quotients (from column 7 of the Air/Soil Volatile Hazard Worksheet). | | ___ |
| 68. Human Health Hazard Score (Table G-1). | 0 1 2 3 4 5 6 | ___ |
| 69. Final Health Hazard Score for air/soil volatile pathway (item [68] × 100/6). | | ___ |
| 70. Sum of Terrestrial Hazard Quotients (from column 8 of the Air/Soil Volatile Hazard Worksheet). | | ___ |
| 71. Ecological Hazard Score (Table G-2). | 0 1 2 3 4 5 6 | ___ |
| 72. Final Ecological Hazard Score for air/soil volatile pathway (item [71] × 100/6). | | ___ |

## CONTAMINANT HAZARD--AIR/SOIL DUST

| | Score (circle one) | Result |
|---|---|---|
| 77. Sum of Health Hazard Quotients (from column 9 of the Air/Soil Dust Hazard Worksheet). | | ___ |
| 78. Human Health Hazard Score (Table G-1). | 0 1 2 3<br>4 5 6 | ___ |
| 79. Final Health Hazard Score for air/soil dust pathway (item [78] × 100/6). | | ___ |
| 80. Sum of Terrestrial Hazard Quotients (from column 10 of the Air/Soil Dust Hazard Worksheet). | | ___ |
| 81. Ecological Hazard Score (Table G-2). | 0 1 2 3<br>4 5 6 | ___ |
| 82. Final Ecological Hazard Score for air/soil dust pathway (item [81] × 100/6). | | ___ |

## HUMAN HEALTH RECEPTORS–SURFACE WATER PATHWAY

| | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|
| 87. Population that obtains drinking water from potentially affected surface water body(ies) downstream | 0 1 2 3 | 3 | ___ | 9 |
| 88. Water use of nearest surface water body(ies) | 0 1 2 3 | 3 | ___ | 9 |
| 89. Population within ½ mi (806 m) of the site | 0 1 2 3 | 1 | ___ | 3 |
| 90. Distance to the nearest installation boundary | 0 1 2 3 | 1 | ___ | 3 |
| 91. Land use and/or zoning within 2 miles (3.2 km) of the site | 0 1 2 3 | 1 | ___ | 3 |
| 92. Sum of items [87] through [91] | | | ___ | 27 |
| 93. Final Human Health Receptors score for surface water pathways (item [92] × 100/27) | | | ___ | |

## ECOLOGICAL RECEPTORS–SURFACE WATER PATHWAYS

| | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|
| 94. Importance/sensitivity of biota/ habitats in potentially affected surface water bodies nearest the site | 0 1 2 3 | 5 | ___ | 15 |
| 95. Presence of "critical environments" within 1.5 miles (2.4 km) of the site | 0 3 | 1 | ___ | 3 |
| 96. Sum of items [94] and [95] | | | ___ | |
| 97. Final Ecological Receptors score for surface water pathways (item [96] × 100/18) | | | ___ | 18 |

## HUMAN HEALTH RECEPTORS–GROUND WATER PATHWAY

| | | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|---|
| 98. | Estimated mean ground water travel time from waste location to nearest downgradient water supply well(s) | 0 1 2 3 | 9 | ___ | 27 |
| 99. | Estimated mean ground water travel time from current waste location to any downgradient surface water body that supplies water for domestic use or for food chain agriculture | 0 1 2 3 | 5 | ___ | 15 |
| 100. | Ground water use of the upper-most aquifer | 0 1 2 3 | 4 | ___ | 12 |
| 101. | Population potentially at risk from ground water contamination | 0 3 6 9 12 18 24 27 36 | 1 | ___ | 36 |
| 102. | Population within ½ mi (806 m) of the site | 0 1 2 3 | 1 | ___ | 3 |
| 103. | Distance to the nearest installation boundary | 0 1 2 3 | 1 | ___ | 3 |
| 104. | Sum of items [98] through [103] | | | ___ | 96 |
| 105. | Final Human Health Receptors score for ground water pathways (item [104] × 100/96) | | | ___ | |

## ECOLOGICAL RECEPTORS–GROUND WATER PATHWAYS

| | | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|---|
| 106. | Estimated mean ground water travel time from waste location to any downgradient habitat or natural areas | 0 1 2 3 | 3 | ___ | 9 |
| 107. | Importance/sensitivity of down-gradient biota/habitats that are confirmed or suspected ground water discharge points | 0 1 2 3 | 3 | ___ | 9 |

## HUMAN HEALTH RECEPTORS–GROUND WATER PATHWAY (concluded)

| | | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|---|
| 108. | Presence of "critical environments" within 1.5 miles (2.4 km) of the site | 0 1 3 | 1 | ___ | 3 |
| 109 | Sum of items 106 through 108 | | | ___ | 21 |
| 110. | Final Ecological Receptors score for ground water pathways (item [109] × 100/21) | | | ___ | |

## HUMAN HEALTH RECEPTORS–AIR/SOIL VOLATILES/DUST PATHWAYS

| | | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|---|
| 111. | Population within 4 mile radius | 0 9 12 15 18 21 24 27 30 | 1 | ___ | 30 |
| 112. | Land use | 0 1 2 3 | 2 | ___ | 6 |
| 113. | Distance to nearest installation boundary | 0 1 2 3 | 1 | ___ | 3 |
| 114. | Sum of items [111] through [113] | | | ___ | 39 |
| 115. | Final Human Health Receptors score for air pathways (item [114] × 100/39) | | | ___ | |

## ECOLOGICAL RECEPTORS–AIR/SOIL VOLATILES/DUST PATHWAYS

| | | Score (circle one) | Multiplier | Score Product (score × mult.) | Maximum Score |
|---|---|---|---|---|---|
| 116. | Distance to sensitive environment | 0 1 2 3 | 2 | ___ | 6 |
| 117. | Presence of "critical environments" within 1.5 mile (2.4 km) of the site | 0 3 | 1 | ___ | 3 |
| 118. | Sum of items [116] and [117] | | | ___ | 9 |
| 119. | Final Ecological Receptors score for air pathways (item [118] × 100/9) | | | ___ | |

## SCORING SUMMARY SHEET

| | | Pathways Score | | Contaminant Hazard Score | | Receptors Score | |
|---|---|---|---|---|---|---|---|
| 120. | Surface water/human health scores | ( ______ item [12] | × | ______ item [49]/[54] | × | ______ item [93] | ) /10,000 |
| 121. | Surface water/ ecological scores | ( ______ item [12] | × | ______ item [52]/[56] | × | ______ item [97] | ) /10,000 |
| 122. | Ground water/human health scores | ( ______ item [22] | × | ______ item [59]/[64] | × | ______ item [105] | ) /10,000 |
| 123. | Ground water/ ecological scores | ( ______ item [22] | × | ______ item [62]/[66] | × | ______ item [110] | ) /10,000 |
| 124. | Air/Soil volatiles human score | ( ______ item [34] | × | ______ item [69] | × | ______ item [115] | ) /10,000 |
| 125. | Air/Soil volatiles ecological scores | ( ______ item [34] | × | ______ item [72] | × | ______ item [119] | ) /10,000 |
| 126. | Air/Soil dust human health scores | ( ______ item [46] | × | ______ item [79] | × | ______ item [115] | ) /10,000 |
| 127. | Air/Soil dust ecological score | ( ______ item [46] | × | ______ item [82] | × | ______ item [119] | ) /10,000 |

## OVERALL SITE SCORE

In this equation use the higher of the following pairs of values ([126] or [124]) and ([127] or [125]).

128. $$\Big[(\underbrace{\_\_\_\_}_{\text{item [120]}})^2 \times 5 + (\underbrace{\_\_\_\_}_{\text{item [121]}})^2 + (\underbrace{\_\_\_\_}_{\text{item [122]}})^2 \times 5 + (\underbrace{\_\_\_\_}_{\text{item [123]}})^2 + (\underbrace{\_\_\_\_}_{\substack{\text{item [124]} \\ \text{or [126]}}})^2 \times 5 + (\underbrace{\_\_\_\_}_{\substack{\text{item [125]} \\ \text{or [127]}}})^2\Big]^{1/2} = \_\_\_\_$$

129. Over all site score = $\underbrace{\_\_\_\_\_\_}_{\text{item [128]}}$ /4.24 = ________

## Appendix B: List of Expert IRP Managers Interviewed

### IRP Managers that Participated in the Sample Test Case to Rank Progress

Sharon A. Geil
Installation Restoration Program Manager
HQ AMC/CEVR, Scott AFB IL

Karl Kneeling
Installation Restoration Program Manager
HQ USAF/CEVR, Bolling AFB DC

T. Wayne Ratliff
Installation Restoration Program Manager
HQ AFMC/CEVR, Wright-Patterson AFB OH

### Additional IRP Managers Interviewed

Jeff K. Mundey
Chief, Environmental Restoration Division.
HQ AFMC/CEVR, Wright-Patterson AFB OH

Major Stuart A. Nelson
DERA Program Manager
HQ USAF/CEVR, Bolling AFB DC

Appendix B: Sample Data Used for Personal Interviews

## SAMPLE IRP SITE DATA

| SITE ID | SITE TYPE | DPM SCORE | CHANGE IN RISK POSSIBLE | CHANGE IN RISK ACHIEVED | % CHANGE ACHIEVED | SITE CLOSED |
|---|---|---|---|---|---|---|
| SITE A | LANDFILL | 62 | 56 | 50 | 90 | Y |
| SITE B | LANDFILL | 61 | 54 | 27 | 50 | N |
| SITE C | LANDFILL | 42 | 36 | 36 | 100 | Y |
| SITE D | LANDFILL | 11 | 9 | 9 | 100 | Y |
| SITE E | LANDFILL | 10 | 9 | 0 | 0 | Y |
| SITE F | SPILL | 42 | 23 | 20 | 87 | N |
| SITE G | SPILL | 40 | 19 | 9.5 | 50 | N |
| SITE H | SPILL | 23 | 11 | 11 | 100 | Y |
| SITE I | SPILL | 11 | 7 | 7 | 100 | N |
| SITE J | SPILL | 5 | 5 | 0 | 0 | Y |
| SITE K | FTA | 39 | 17 | 15 | 88 | N |
| SITE L | FTA | 31 | 12 | 0 | 0 | Y |
| SITE M | FTA | 29 | 17 | 8.5 | 50 | N |
| SITE N | FTA | 24 | 10 | 10 | 100 | Y |
| SITE O | FTA | 20 | 9 | 0 | 0 | Y |
| SITE P | UST | 39 | 33 | 33 | 100 | Y |
| SITE Q | UST | 39 | 33 | 33 | 100 | N |
| SITE R | UST | 31 | 25 | 12.5 | 50 | N |
| SITE S | UST | 19 | 15 | 15 | 100 | Y |
| SITE T | UST | 18 | 12 | 6 | 50 | Y |

## SAMPLE IRP SITE DATA

Site ID - Fictitious name for sample IRP sites from which actual DPM data was used.

DPM Score - DPM scores submitted to the Air Staff for the sample sites. The sites were scored by IRP managers at the bases.

Change in Risk Possible - This is the amount the DPM score could be reduced by changing all of the input parameters that can be affected by remedial actions.

Change in Risk Achieved - This is fictitious data made to represent a variety of typical site status scenarios.

% Change Achieved - This is the Change in Risk Achieved divided by the Change in Risk Possible, then multiplied by 100 to get a percentage.

Site Closed - This is fictitious data representing whether the sites have been closed out (by Air Staff's guidance for IRP scorecard).

### Instructions

Please provide your expert opinion on how you would rank the 20 sites base on what has been accomplished as a result of the IRP. Please order the sites from 1 to 20. You may use your own personal opinions or beliefs and /or various management strategies used to manage the IRP. I would like to have a brief personal interview to discuss how you weighed or considered each of the factors to rank the accomplishments at the sample sites.

I appreciate your interest and help in this research. If you have any questions please contact me. My home phone number is (513) 429-1148 or you can leave a message at AFIT/DE, (513)
255-2156, DSN 785-2156.

## Appendix D: List of Acronyms

| | |
|---|---|
| ADI | Average Daily Intake |
| ADPM92 | Automated Defense Priority Model, version FY 92 |
| AF | Air Force |
| AI | Artificial Intelligence |
| CERCLA | Comprehensive Environmental Response, Compensation and Liability Act |
| DERA | Defense Environmental Restoration Account |
| DERP | Defense Environmental Restoration Program |
| DIM | Displaced Ideal Model |
| DOD | Department of Defense |
| DOE | Department of Energy |
| DPM | Defense Priority Model |
| EPA | U.S. Environmental Protection Agency |
| FTA | Fire Training Area |
| HARM | Hazard Assessment Risk Model |
| HQ | headquarters |
| HRS | Hazard Ranking System |
| IRP | Installation Restoration Program |
| MAJCOM | Major Command |
| MCDM | Multi-Criteria Decision Model |
| MEPAS | Multimedia Environmental Pollutant Assessment System |
| NAS | National Academy of Sciences |
| NPL | National Priority List |
| OSD(E) | Office of the Assistant Secretary of Defense (Environment) |

| | |
|---|---|
| PA | Preliminary Assessment |
| QC | Quality Control |
| RI | Remedial Investigation |
| SARA | Superfund Amendments and Reauthorization Act |
| SI | Site Inspection |
| USAF/CEV | U.S. Air Force Civil Engineering, Directorate of Environmental Management |
| USAF/CEVR | U.S. Air Force Civil Engineering, Directorate of Environmental Management, Installation Restoration Division |
| UST | Underground Storage Tank |

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## Vita

Scott Edwards Jr. was born on 27 September 1958 in Jacksonville, Florida. He graduated from Orange Park High School in Orange Park, Florida in 1976. He then attended the University of Alabama where he received the degree of Bachelor of Science in Geology in December 1981. Upon graduation he held the position of Hydrogeologist in a private geological services firm in Gainesville, Florida until October 1983. From 1983 to 1988 he held the position of Hydrologist for the St. John's River Water Management District in Palatka, Florida where he was a project manager for several groundwater resources investigations. In May of 1988 he began federal civil service on the Headquarters Military Airlift Command environmental management staff at Scott Air Force Base, Illinois. He held the position of Hydrologist and was the Installation Restoration Program Manager. In 1991 he was selected to attend the Graduate Engineering and Environmental Management Program at the Air Force Institute of Technology's School of Engineering.

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13. ABSTRACT (Maximum 200 words)

To properly manage the Installation Restoration Program (IRP) in the future, the Air Force (AF) needs a method to assess progress based on improvements in environmental conditions. An integral part of evaluating progress toward protecting human health and the environment is the assessment of risk reduction as a result of cleanup actions.

The AF currently uses the Defense Priority Model (DPM) to assist in setting priorities for funding remedial actions at IRP sites. The DPM provides a numerical score for IRP sites representing the relative potential risk based on the environmental conditions at a site before remedial actions are taken. This study investigates using the DPM to provide an indicator or progress based on improvements in environmental conditions at IRP sites.

Rescoring the DPM to represent site condtions after remedial actions shows a reduction in relative risk as contaminant levels and transport potential are changed. A multi-criteria decision modeling technique was used to combine the relative risk data with other administrative measures of progress currently used by the AF. The results provide a method to rank the accomplishments at IRP sites.


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